

DESCRIPTION

SURFACE-EMISSION LASER DIODE AND FABRICATION PROCESS
THEREOF

5 TECHNICAL FIELD

The present invention relates to surface-emission laser diodes and the fabrication process thereof.

BACKGROUND ART

10 A surface-emission laser diode (surface-emission semiconductor laser) is a laser diode that emits light in a vertical direction to the substrate and is used for civil purposes, such as optical source of optical telecommunication including optical
15 interconnection, optical source of optical pickup devices, optical source of image forming apparatuses, and the like.

Patent Reference 1 Japanese Laid-Open Patent Application 2002-164621

20 Patent Reference 2 Japanese Laid-Open Patent Application 9-107153 official gazette

Patent Reference 3 Japanese Laid-Open Patent Application 2001-60739

25 Patent Reference 4 Japanese Laid Open Patent Application 2001-168461

Non-patent Reference 1 IEEE Photonics
Technology Letters, Vol. 10, No. 12, pp. 1676-
1678, 1998 (Tokyo Institute of Technology)

Non-patent Reference 2 IEEE Photonics
5 Technology Letters, Vol. 12, No. 6, pp. 603-605, 2000
(Wisconsin Univ.)

DISCLOSURE OF THE INVENTION

With a surface-emission laser diode for
such applications, it is required that the laser
10 diode has a large gain for the active layer, low
threshold value, high output, excellent reliability,
and controlled polarization direction.

Particularly, surface-emission laser diodes
have a tendency of providing small optical output as
15 compared with edge-emission laser diodes in view of
the small volume of the active layer. Thus, there are
many cases in which demand of increased output is
imposed to such surface-emission laser diodes. One
approach of increasing the optical output is to
20 suppress the temperature rise of the optical emission
part.

First, explanation will be made for a
typical device structure of surface-emission laser
diode and description will be made further with
25 regard to the measures taken against heat.

Figure 1 is a diagram showing an example structure of general surface-emission laser diode. It should be noted that the example of Figure 1 is a surface-emission laser diode having InGaAs/GaAs for the active layer and using the current confinement structure formed by selective oxidization of an AlAs layer.

The general surface-emission laser diode shown in Figure 1 is produced in the following manner.

By an MOCVD process or MBE process, there is formed a stack of films by consecutively stacking, on an n-GaAs single crystal substrate 11, an n-AlGaAs/n-AlGaAs lower semiconductor multilayer reflector (DBR: distributed Bragg reflector) 12, a lower GaAs spacer layer 13, an AlGaAs/AlGaAs-MQW active layer 14, an upper AlGaAs spacer layer 15, an AlAs layer for selective oxidation 16, and p-AlGaAs/p-AlGaAs upper semiconductor multilayer reflector (DBR).

Next, the stacked film is processed to form a mesa structure by a dry etching process. With this process, it is commonly practiced to conduct the etching such that the etching surface reaches a region inside the lower semiconductor DBR 12.

Next, the AlAs layer for selective oxidation 16 having the sidewall surface exposed by the dry etching process is processed in water vapor, such that there occurs oxidation at the peripheral
5 part thereof, to form an insulation layer of Al_xO_y in such a peripheral part. Thereby, there is formed a current confinement structure that restricts the path of the device drive current only to the AlAs region at the central part where the oxidation has not taken
10 place.

Next, the peripheral part of the mesa structure is filled with an insulation film 18, and a p-side electrode 19 and an n-side electrode 20 are formed at predetermined locations. With this,
15 fabrication of the surface-emission laser diode of Figure 1 is completed.

Meanwhile, with such a surface-emission laser diode, it is preferable to reduce the height of the mesa structure and thereby to reduce the heat
20 resistance to the substrate for the purpose of improving heat dissipation from the active layer 14. However, with the mesa formation process conducted by a dry etching process, fluctuation in the etching depth of $\pm 10\%$ or more is not unusual, and further in
25 view of the possible fluctuation of etching depth

inside the specimen, it is inevitable to set the height of the mesa structure to be larger than the height which is actually necessary.

Patent Reference 1 shows the construction
5 that reduces heat resistance.

With the construction shown in Patent Reference 1, AlAs, having a much larger thermal conductivity as compared with AlGaAs, is used for the low refractive index layers in the majority part of
10 the DBR located at the lower part of the lower semiconductor DBR. On the other hand, conventional AlGaAs is used for the low refractive index layer in the upper part of lower semiconductor DBR. The reason of this is to avoid the situation that the etching
15 surface reaches inside the lower part AlAs-DBR and there takes place oxidation at the edge surface of the AlAs layer of lower part AlAs-DBR exposed at the mesa sidewall surface at the time of conducting the oxidation processing of the AlAs layer for selective
20 oxidation later. When this occurs, the active part in the device is insulated or there occurs increase of device resistance. The reason that such a situation arises is that the oxidation rate of AlGaAs relies heavily upon the Al content and that there occurs
25 increase in the oxidation rate with increase of the

Al content. Thus, the oxidation rate becomes the largest with AlAs.

In order to avoid this problem, Patent Reference 1 forms the upper AlGaAs-DBR by using
5 AlGaAs of small oxidation rate and controls the bottom surface of etching such that the bottom surface of etching is located in this upper AlGaAs-DBR. Thereby, exposure of the AlAs edge surface of the lower AlAs-DBR is avoided. With such an upper
10 AlGaAs-DBR, it is preferable that the pair number is equal to or smaller than $4/7$ of the entire pair number as set forth in Patent Reference 1. Particularly, it is desirable to set the pair number to 10 pairs or less.

15 However, with the approach of controlling the bottom surface of etching such that the bottom surface of etching is located in the upper AlGaAs-DBR of only about 10 pairs by way of controlling the etching time, there is caused remarkable decrease of
20 yield, and there arises a problem in that large fluctuation occurs in the position of the bottom surface of etching in the upper AlGaAs-DBR.

Therefore, in order to achieve the object of providing measures against heat while maintaining
25 high yield, control of the mesa formation process by

dry etching process becomes important. For this, it is desirable to carry out monitoring of the etching process.

For the monitoring method of dry etching process, there is a known method of plasma atomic emission spectrometry. Further, there is a method that irradiates the surface of the specimen to be etched with light, wherein this method monitors the intensity of the reflection light and detects the etching depth from the change of the interference intensity of the film. From the viewpoint that there is no need of providing observation window and in view of the fact that the method is well established and that there are commercially available instruments, it is thought advantageous to use the plasma atomic emission spectrometry.

With the monitoring method that uses this plasma atomic emission spectrometry, the change of emission intensity corresponding to the semiconductor film composition is detected by monitoring the atomic emission intensity of Ga at 417nm or the time change of the ratio of the atomic emission intensity of Ga at 417nm to the atomic emission intensity of Al at 396nm. In the case of the specimen formed primarily of repetition of the layers of two compositions as in

the case of the layered structure of the surface-emission laser diode, this atomic emission intensity change draws an oscillatory waveform.

However, in the semiconductor film used for
5 the surface-emission laser diode that oscillates at the laser oscillation wavelength of a GaAs active layer (about 850nm), in particular, the change of Ga composition or Ga/Al composition ratio is small. Further, the film thickness of the DBR or cavity is
10 small in correspondence to the wavelength. Thus, the amplitude of the oscillatory waveform of the plasma atomic emission spectrometry becomes small. Thereby, it is not easy to carry out the monitoring. Further, in the case the specimen to be etched has large size,
15 there arises a problem in that monitoring becomes difficult because of the distribution of etching rate inside the specimen.

Meanwhile, it is known that excellent carrier confinement to the active layer is attained
20 in the surface-emission laser diode of the 850nm band and 980nm band.

For example, GaAs is used for the quantum well active layer and AlGaAs is used for the barrier layer and the spacer layer (cladding layer) of a
25 surface-emission laser diode of the 850nm band.

Further, with such a surface-emission laser diode of the 850nm band, it is possible to use the current confinement structure that uses a high-performance AlGaAs-system reflector (DBR) and the current
5 confinement structure that uses an Al oxide film.

Further, various proposals have been made with regard to polarization control of such a surface-emission laser diode. For example, there is proposed a method of providing anisotropy in the
10 outer shape of the active layer as viewed from the optical emission direction. Particularly, Non-Patent Reference 1 shows that polarization control is possible by anisotropy of optical gain realized by using a (311)B substrate, in other words a so-called
15 off-substrate that is inclined from (100) by 25° in the (111)B direction, such that the optical gain in the inclined direction is increased. Further, it is shown that similar effect is obtained also with a (311)A substrate.

20 However, with the technology of Non-Patent Reference 1, there is a drawback in that it is difficult to conduct crystal growth on the heavily inclined (311)B substrate as compared with the crystal growth on the (100) substrate and that
25 crystal growth on the (311)A substrate is even more

difficult.

Further, in any of these substrates in which the substrate is heavily inclined, the cost of the substrate is increased by twice or more and it is
5 difficult to carry out cleaving process. Further, handling of the substrate is difficult.

Meanwhile, the surface-emission laser diode of the wavelength shorter than 850nm is realized by increasing the bandgap of the quantum well active
10 layer by adding thereto Al.

For example, there is a proposal of a surface-emission laser diode of the 780nm band in which Al is added to the quantum well active layer by about 12% in terms of the compositional ratio.

15 However, such a surface emission laser diode of the band shorter than 850nm, there is caused a decrease in the band discontinuity between the quantum well active layer and the barrier layer or the spacer layer, and the efficiency of carrier
20 confinement to the active layer is decreased.

Thereby, there arises a problem in that it is difficult to attain good temperature characteristics as compared with the surface-emission laser diode of the 850nm band. Further, because the active layer is
25 added with active Al, there is a tendency that oxygen

is incorporated into the active layer during the growth or processing thereof, while this leads to the problem of formation of non-optical recombination center, which in turn invites degradation of efficiency of optical emission and degradation of reliability.

Patent Reference 2 proposes a surface-emission laser diode (780nm band) that uses an Al-free active region (quantum well active layer and the layers adjacent thereto) in a surface-emission laser diode of the wavelength band of 850nm or shorter for the purpose of suppressing the formation of non-optical recombination center.

With this conventional surface-emission laser diode, GaAsP having a tensile strain is used for the quantum well active layer, and GaInP having a compressive strain is used for the barrier layer. Further, lattice matched GaInP is used for the spacer layer (the layer between the cladding layer and the first and third quantum well active layer), and AlGaInP is used for the cladding layer. According to the technology of Patent Reference 2, reliability of the surface-emission laser diode is improved in view of use of the Al-free composition of the active region.

Further, Non-Patent Reference 2 proposes a surface-emission laser diode of the 780nm band that uses GaInPAs having a compressive strain for the quantum well active layer for the purpose of

5. attaining the effect of Al-free active region and further for the purpose of increasing the gain of the active layer, wherein Non-Patent Reference 2 further teaches the use of lattice matched GaInP or GaInP having a tensile strain for the barrier layer and the

10 use of lattice matched AlGaInP for the spacer layer (the layer between the cladding layer and the first and third quantum well active layers) and further the use of AlGaInP (having Al composition larger than the spacer layer) for the cladding layer.

15 With the surface-emission laser diode of Non-Patent Reference 2, the barrier layer has a lattice matched composition, and thus, the barrier layer has a larger bandgap as compared with the compressive strain composition, and thus, the

20 efficiency of carrier confinement is improved as compared with the structure of Patent Reference 2 mentioned before.

With regard to polarization control, Patent Reference 3 shows the technology of using a substrate

25 having a surface orientation inclined in the

direction of (111)A surface or (111)B surface from
the (100) surface orientation by the angle
(inclination angle) of $15 - 40^\circ$, wherein this
technology uses the anisotropy of optical gain in
5 combination with the multiple quantum well active
layer of InAlGaAs and InGaAsP having a compressive
strain for increasing the optical gain in the
inclined direction.

Further, Patent Reference 4 shows the
10 method that forms the mesa shape in a circular,
elliptical or elongated circular shape and sets the
direction of the major axis in the direction of
(111)A surface or (111)B surface from (100). In this
case, a substrate having a surface orientation offset
15 by 2° (including $-5^\circ - +5^\circ$) in the [110] direction
from (100) is used. It should be noted that this is
not the substrate inclined in the A surface or B
surface direction.

However, it has not been realized a
20 surface-emission laser diode of the wavelength
shorter than 850nm and at the same time having a
large gain for the active layer and small threshold
value, high output power, excellent reliability and
controlled polarization direction.

25 Thus, while Patent Reference 2 can provide

improved reliability in view of the use of Al-free active layer, the reference is silent about the control method of polarization. Further, while Non-Patent Reference 2 provides a structure of excellent
5 carrier confinement, it is silent about the control method of polarization. Further, while Patent Reference 3 enables control of polarization direction, it is totally indifferent to reliability or structure matched to the property of the
10 materials. Further, while Patent Reference 4 can control the polarization direction, it is totally indifferent about achieving high gain and long lifetime for the surface-emission laser diode of the wavelength shorter than 850nm.

15 Further, in the case a material of (Al)GaInP system is used for the material forming the cavity region sandwiched by the upper and lower reflectors as described in Non-Patent Reference 2, it is known that there arises large increase of
20 threshold current because of separation (segregation) of In such as carry-over of In into the AlGaAs layer at the interface between the cavity region and the upper reflector, which is formed by the material of the AlGaAs system.

25 Further, AlGaInP, a quaternary mixed

crystal, has large thermal resistance, and there also arises a problem with a material of the (Al)GaInP system in that Zn (zinc), which is used for the p-type dopant, easily causes diffusion.

5 Thus, it has not been realized conventionally to provide a surface-emission laser diode of the wavelength shorter than 850nm, having large gain for the active layer and low threshold value, high output, excellent reliability and
10 controlled polarization direction.

 Thus, it is the object of the present invention to provide, in a surface-emission laser diode having small Ga content or small change of Ga/Al ratio in a semiconductor distributed Bragg
15 reflector (DBR) and having improved heat dissipation, a construction that can improve the controllability of etching at the time of forming the mesa structure by etching a laser stacking structure, and to provide a surface-emission laser diode having such a
20 construction and capable of performing high output operation.

 In addition, the present invention has an object of providing, in a surface-emission laser diode of the wavelength shorter than 850nm, the
25 surface-emission laser diode of excellent reliability

and a high-output surface-emission laser diode of low threshold value having a large gain of active layer.

Further, the present invention has an object of providing, in a surface-emission laser diode of the wavelength shorter than 850nm, the surface-emission laser diode of excellent reliability, having large gain for the active layer and low threshold value, high output power and controlled polarization direction.

Further, the present invention provides a surface-emission laser diode array, an image forming apparatus, an optical pickup system, an optical transmission module, an optical transceiver module and an optical telecommunication system in which the foregoing surface-emission laser diode is integrated.

In a first aspect, the present invention provides a surface-emission laser diode, comprising:

a semiconductor substrate;

a cavity region formed over said semiconductor substrate, said cavity region comprising: an active layer structural part including at least one quantum well active layer producing a laser light and a barrier layer; and a spacer layer provided in a vicinity of said active layer structural part, said spacer layer comprising at

least one material; and

an upper reflector and a lower reflector
provided over said semiconductor substrate
respectively at a top part and a bottom part of said
5 cavity region,

said cavity region, said upper reflector
and said lower reflector forming a mesa structure
over said semiconductor substrate,

said upper reflector and said lower
10 reflector constituting a semiconductor distributed
Bragg reflector having a periodic change of
refractive index and reflecting an incident light by
interference of optical waves,

at least a part of said semiconductor
15 distributed Bragg reflector being formed of a layer
of small refractive index of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) and a
layer of large refractive index of $\text{Al}_y\text{Ga}_{1-y}\text{As}$
($0 \leq y < x \leq 1$),

said lower reflector being formed of a
20 first lower reflector having a low-refractive index
layer of AlAs and a second lower reflector formed on
said first lower reflector, said second lower
reflector having a low-refractive index layer of
 AlGaAs ,

25 wherein any one layer constituting said

cavity region contains In.

In a second aspect, the present invention provides a surface-emission laser diode, comprising:

a (100) GaAs substrate having a surface
5 orientation inclined in a direction of a (111)A surface by an angle of 5° to 20° ;

a cavity region provided over said GaAs substrate, said cavity region including an active layer structural part comprising at least one layer
10 of quantum well active layer producing a laser light and barrier layers, and a spacer layer provided in a vicinity of said active layer structural part, said spacer layer comprising at least one material; and

an upper reflector and a lower reflector
15 provided at a top part and a bottom part of said cavity region,

said cavity region and said upper and lower reflectors forming a mesa structure over said GaAs substrate,

20 said upper reflector and said lower reflector comprising a semiconductor distributed Bragg reflector having a periodic change of refractive index and reflecting an incident light by interference of optical waves,

25 at least a part of said semiconductor

distributed Bragg reflector being formed of a layer of small refractive index of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) and a layer of large refractive index of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$),

5 a part of said spacer layer comprising $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$),

 said quantum well active layer comprising $\text{Ga}_c\text{In}_{1-c}\text{PdAs}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$),

 said barrier layers comprising $\text{Ga}_e\text{In}_{1-e}\text{PfAs}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$),
10

 said quantum well active layer having a compressive strain,

 said active layer structural part having a shape anisotropy elongated in a direction of a (111)A
15 surface as viewed from a direction of light emission.

 In a third aspect, the present invention provides a method of fabricating a surface emission laser diode, said surface emission layer diode comprising, over a semiconductor substrate: a cavity
20 region comprising an active layer structural part including at least one quantum well active layer producing a laser light and barrier layers, and a spacer layer of at least one material provided in a vicinity of said active layer structural part; and an
25 upper reflector and a lower reflector provided at a

top part and a bottom part of said cavity region,
said method comprising the steps of:

forming a stacked structure including said
lower reflector, said cavity region and said upper
5 reflector over said semiconductor substrate; and

forming a mesa structure by patterning said
stacked film by dry etching,

said step of forming said stacked structure
including a step of incorporating In to any one layer
10 constituting said cavity region,

said step of forming said mesa structure by
said dry etching comprises a step of controlling a
height of said mesa structure by monitoring light
emission of In.

15 In a forth aspect, the present invention
provides a surface-emission laser diode, comprising:

a GaAs substrate;

a cavity region formed over said GaAs
substrate, said cavity region including at least one
20 quantum well active layer producing a laser light and
barrier layers; and

an upper reflector and a lower reflector
provided at a top part and a bottom part of said
cavity region over said GaAs substrate,

25 said upper reflector and/or said lower

reflector including a semiconductor Bragg reflector,
at least a part of said semiconductor
distributed Bragg reflector comprising a
semiconductor layer containing Al, Ga and As as major
5 components,

wherein there is provided, between said
active layer and said semiconductor layer that
contains Al, Ga and As as major components, a
semiconductor layer containing Al, In and P as major
10 components such that said semiconductor layer
containing Al, In and P as major components is
provided adjacent to said semiconductor layer that
contains Al, Ga and As as major components,

an interface between said semiconductor
15 layer containing Al, Ga and As as major components
and said semiconductor layer containing Al, In and P
as major components being formed coincident to a
location of a node of electric field strength
distribution.

20 In a fifth aspect, the present invention
provides a surface-emission laser diode, comprising:

a GaAs substrate;

a cavity region formed over said GaAs
substrate and having at least one quantum well active
25 layer producing a laser light and barrier layers; and

an upper reflector and a lower reflector provided at a top part and a bottom part of said cavity region over said GaAs substrate,

said upper reflector and/or lower reflector including a semiconductor distributed Bragg reflector,

at least a part of said semiconductor distributed Bragg reflector comprising a semiconductor layer containing Al, Ga and As as major components,

there being provided, between said active layer and said semiconductor layer containing Al, Ga and As as major components, a $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer adjacent to said semiconductor layer containing Al, Ga and As as major components,

said $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer being added with Mg (magnesium) as a p-type dopant,

said semiconductor layer containing Al, Ga and As as major components being added with C (carbon) as a p-type dopant.

In a sixth aspect, the present invention provides a surface-emission laser diode, comprising:

a GaAs substrate;

a cavity region formed over said GaAs substrate, said cavity region including at least one

quantum well active layer producing a laser light and barrier layers; and

an upper reflector and a lower reflector provided at a top part and a bottom part of said cavity region over said GaAs substrate,

said upper reflector and/or lower reflector including a semiconductor distributed Bragg reflector,

at least a part of said semiconductor distributed Bragg reflector comprising a semiconductor layer containing Al, Ga and As as major components,

there being provided, between said active layer and said semiconductor layer containing Al, Ga and As as major components, a $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer adjacent to said semiconductor layer containing Al, Ga and As as major components,

said $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer being a semiconductor layer formed of a short period superlattice structure of AlInP and GaInP.

In a seventh aspect, the present invention provides a surface-emission laser diode, comprising:

a GaAs substrate;

a cavity region formed over said GaAs substrate, said cavity region including at least one

quantum well active layer producing a laser light and barrier layers; and

an upper reflector and a lower reflector provided at a top part and a bottom part of said cavity region over said GaAs substrate,

said upper reflector and/or lower reflector including a semiconductor distributed Bragg reflector,

at least a part of said semiconductor distributed Bragg reflector comprising a low refractive index layer of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) and a high refractive index layer of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$),

one of said low refractive index layers constituting said upper reflector and/or said lower reflector and located closest to said active layer comprising $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$),

an interface between said cavity region and said low refractive index layer of said upper reflector and/or said lower reflector located closest to said active layer being coincident to an anti-node of an electric strength distribution.

According to said first aspect of the present invention, any one layer constituting the cavity region contains In, and thus, precision and reproducibility of mesa etching is improved by

detecting exposure of said In-containing layer at the time of the mesa etching of the laser lamination structure comprising the cavity and the upper and lower semiconductor DBRs. Even in the case the lower
5 semiconductor DBR contains AlAs/(Al)GaAs-DBR of excellent heat dissipation, it is possible to realize a construction in with the AlAs/(Al)GaAs-DBR is provided to the neighbor of the cavity. With such a construction, temperature rise at the time of laser
10 driving is suppressed and a high output power surface-emission laser diode of excellent temperature characteristics is provided. At the same time, it becomes possible to provide a surface-emission laser diode having excellent uniformity in the laser
15 characteristics and characterized by excellent reproducibility in the processing and excellent yield.

Particularly, by incorporating In into the upper or lower spacer layer constituting the active
20 region and having much larger thickness as compared with the active layer structural part, it becomes possible to form the mesa structure with further improved reproducibility and further improved precision, and with this, it becomes possible to form
25 a surface-emission laser diode of further improved

temperature characteristics, higher output power and further improved uniformity in laser characteristics, with higher reproducibility of processing and with higher yield.

5 Further, by forming the semiconductor DBR constituting the second lower reflector in the surface-emission laser diode according to the first aspect, such that the semiconductor DBR has the thickness of 10 pairs or less, the thickness of the semiconductor DBR is set to be larger than the
10 precision of the mesa etching and at the same time minimum. With this, temperature rise at the time of driving is suppressed further, and a surface-emission laser diode of high output power is obtained with
15 excellent temperature characteristics.

 Further, by forming a part of the spacer layer of the surface-emission laser diode according to the first aspect of the present invention by $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) and by forming the
20 quantum well active layer by $Ga_cIn_{1-c}P_dAs_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$), and further by forming the barrier layer by $Ga_eIn_{1-e}P^fAs_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$), and further by using an AlGaInP material and thus $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) for a part of the spacer layer, it becomes
25 possible to increase the bandgap difference between

the spacer layer and the quantum well active layer as compared with the case of forming the spacer layer by the AlGaAs system. Thereby, there is achieved improvement of carrier confinement efficiency, and it becomes possible to realize a high-output laser having a further lower threshold value in combination with the excellent heat dissipation effect pertinent to such a structure.

Further, with the surface emission laser diode according to the first aspect of the present invention, it should be noted that a GaInPAs material is used for the barrier layer and the quantum well active layer, and thus, the quantum well active layer is formed of $\text{Ga}_c\text{In}_{1-c}\text{P}_d\text{As}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$), and that the barrier layers are formed of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$). Thus, according to the first feature of the present invention, the active layer structural part formed of the quantum well active layer and the layer adjacent thereto does not contain Al. With this, the problem of incorporation of oxygen into the active layer structural part by Al, and associated problem of formation of non-optical recombination center, is suppressed, and a surface-emission laser diode of long lifetime is realized.

Further, by forming the quantum well active

layer with a compressive strain composition with the surface-emission laser diode according to the first aspect such that a compressive strain is accumulated in the quantum well active layer, the carrier

5 confinement effect is augmented with the effect of the strain, and the optical gain of the active layer structural part is increased further. Further, improvement of heat dissipation is added to the foregoing. Thereby, the threshold value is decreased

10 further. Thus, it becomes possible to realize a surface-emission laser diode of extremely high efficiency and high output power. Further, with decrease of the threshold value attained by the improvement of carrier confinement efficiency and

15 further by the increase of gain as a result of use of the strained quantum well active layer, it becomes possible to decrease the reflectivity of the DBR at the exit side of light (upper semiconductor DBR). As a result of decrease of the reflectivity of the DBR

20 at the optical exit side, a further increase of the optical power becomes possible.

Further, because the semiconductor substrate is a (100) GaAs substrate having a surface orientation inclined in the direction of a (111)A

25 surface with an angle in the range from 5° to 20° (in

other words, as a result of use of the (100) GaAs substrate having the surface orientation inclined in the direction of the (111)A surface with the angle of 5° to 20° by taking into consideration the surface orientation of the substrate) in the surface-emission laser diode according to the first aspect of the present invention, adversary effects to the device characteristics of the semiconductor layer, such as decrease of bandgap caused by formation of natural super lattices or deterioration of surface morphology or formation of non-optical recombination centers caused by hillock (hill-like defect), are reduced.

Further, with the surface-emission laser diode according to the first aspect, which uses the (100) GaAs substrate having the surface orientation inclined in the direction of the (111)A surface within the angular range of 5° to 20° (in other words the (100)GaAs substrate having the surface orientation inclined in the direction of the (111)A surface within the angular range of 5° to 20° with regard to the control of polarization), it is not possible to attain the polarization control effect as in the case of using the (311)B substrate (corresponds to 25° inclination) currently drawing attention, and the anisotropy of optical gain

attained with the use of inclined substrate becomes inevitably small. With the surface-emission laser diode according to the first aspect of the present invention, the foregoing decrease of anisotropy of optical gain can be compensated for by providing a compressive strain to the quantum well active layer and induce increase of anisotropy of the optical gain. Thereby, it becomes possible to control the polarization direction effectively. Thus, with the present invention, there is induced a synergistic effect of improvement of heat dissipation efficiency and increase of gain of the active layer structural part, and it becomes possible to realize a high output power surface-emission laser diode oscillating at a wavelength shorter than 850nm and at the same time having low threshold value, excellent reliability and controlled polarization direction.

Next, according to the second aspect, with the use of the AlGaInP material, and thus $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) for a part of the space layer, it becomes possible to secure a large bandgap between the spacer layer and the quantum well active layer as compared with the case of forming the spacer layer with the AlGaAs system, and the efficiency of carrier confinement is improved. Further, the

threshold of laser oscillation is decreased and it becomes possible to increase the output.

With the surface-emission laser diode of the second aspect, too, the active layer structural part formed of the quantum well layer and the layer adjacent thereto has an Al-free construction as a result of use of GaInPAs material for the barrier layers and the quantum well active layer, and as a result, incorporation of oxygen into the active layer structure by oxygen is reduced, and formation of the non-recombination centers is suppressed. With this, a surface-emission laser diode of long lifetime is realized.

Further, with the present invention, it becomes possible to decrease the threshold value of laser oscillation further with the effect of the compressive strain, by using a compressive strain composition for the quantum well active layer, and it becomes possible to increase the efficiency of laser oscillation and obtain large output.

Further, with the surface-emission laser diode of the second aspect, too, there is caused further decrease of threshold value of laser oscillation because of the improvement of efficiency of carrier confinement to the active layer structural

part and because of improvement of gain by the use of the strained quantum well active layer, and it becomes possible to decrease the reflectivity of the exit-side DBR. Thereby, it becomes possible to obtain
5 further higher output.

Further, with the surface-emission laser diode according to the second aspect of the present invention, it becomes possible, with the use of the (100)GaAs substrate having a surface orientation
10 inclined in the direction of a (111)A surface with an angle within the range of 5° to 20° by taking into consideration the effect of the surface orientation of the substrate, to suppress the adversary the effects to the device characteristics of the laser
15 such diode as decrease of bandgap caused by formation of natural super lattices, deterioration of surface morphology caused by hillocks (hill-like defect), formation of non-optical recombination centers, or the like.

20 With the polarization control, the surface-emission laser diode according to the second aspect of the present invention cannot utilize the effect attained by using the (311)B substrate, which is through most promising at the present juncture as
25 noted before, and the anisotropy of optical gain

associated with the use of inclined substrate becomes inevitably small. With the present invention, this decrease is compensated for, by increasing the anisotropy of optical gain attained by providing a
5 compressive strain to the quantum well active layer, and by increasing the optical gain in the inclined direction of the substrate (111)A surface direction) by providing anisotropy in the outer shape of the active layer as viewed from the optical emission
10 direction of the surface-emission laser diode. With this, control of polarization direction becomes extremely easy.

Thus, according to the surface-emission laser diode of the second aspect of the present
15 invention, it becomes possible to realize a high output power surface-emission laser diode oscillating at the wavelength shorter than 850nm and having a large optical gain for the active layer structural part, small threshold value of laser oscillation,
20 excellent reliability, and controlled polarization plane.

Further, with the surface-emission laser diode of the second aspect of the present invention, it becomes possible to increase the band
25 discontinuity to the quantum well active layer by

accumulating a tensile strain in the barrier layers. Thereby, it becomes possible to increase the gain. With this, the threshold value of laser oscillation is decreased and the surface-emission laser diode becomes possible to perform high output power operation. With the material of the GaInPAs system, it should be noted that the semiconductor material constituting the barrier layer can increase the bandgap by decreasing the lattice constant.

10 Further, according to the surface-emission laser diode of the second aspect of the present invention, it becomes possible to realize a surface-emission laser diode of the oscillation wavelength larger than about 680nm. Further, as a result of the use of the AlGaInP system material for the spacer layer, it becomes possible to realize the carrier confinement equivalent to or superior to the case of the surface-emission laser diode of the 780nm band that uses the active layer of the AlGaAs system, even in the case the active layer, formed of the quantum well layer and barrier layer, is formed of a material free from Al, as long as the compositional wavelength is 680nm or longer. Further, the effect of the strained quantum well active layer is added thereto. Thus, it becomes possible to realize the

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characteristics equivalent to or superior to the surface-emission layer diode of the 780nm band that has the active layer of the AlGaAs system.

Further, according to the third aspect of
5 the present invention that provides the method of fabricating a surface emission laser diode, said surface emission layer diode comprising, over a semiconductor substrate: a cavity region comprising an active layer structural part including at least
10 one quantum well active layer producing a laser light and barrier layers, and a spacer layer of at least one material and provided in a vicinity of said active layer structural part; and an upper reflector and a lower reflector provided at a top part and a
15 bottom part of said cavity region, said method comprising the steps of: forming a stacked structure including said lower reflector, said cavity region and said upper reflector over said semiconductor substrate; and forming a mesa structure by patterning
20 said stacked film by dry etching, said step of forming said stacked structure including a step of incorporating In to any one layer constituting said cavity region, said step of forming said mesa structure by said dry etching comprises a step of
25 controlling a height of said mesa structure by

monitoring light emission of In, it becomes possible to detect the cavity part positively in the foregoing dry etching process, and with this, it becomes possible to form the mesa structure with good reproducibility and with excellent precision. According to the present invention, it becomes possible to fabricate such a surface-emission laser diode with good reproducibility and good yield.

By providing, in a surface-emission laser diode according to the fourth or seventh aspects of the present invention, the interface between the semiconductor layer containing Al, Ga and As as major components and the semiconductor layer containing Al, In and P as major components to be coincident to a location of a node of electric field strength distribution, it becomes possible to decrease the effect of optical absorption at the foregoing interface significantly, even in the case there is caused some segregation of In at the time of crystal growth of the semiconductor layer containing Al, Ga and As as the major components on the semiconductor layer containing Al, In and P as the major components, and it becomes possible to suppress the adversary effect of increase of threshold value caused by the segregation of In.

By adding, in the surface-emission laser diode according to the fifth or seventh aspect, Mg (magnesium) to the semiconductor layer containing Al, In and P as the major components as a p-type dopant, and by adding C (carbon) to the semiconductor layer containing Al, Ga and As as the major components as a p-type dopant, it becomes possible to suppress the diffusion of dopant and reduce the memory effect, and it becomes possible to carry out the doping with good controllability. Thereby, a doping profile near the designed profile is obtained, and degradation of the crystal quality of the active layer is suppressed. With this, a high output power surface-emission laser diode having a low threshold value can be realized easily.

Further, with the surface-emission laser diode according to the sixth or seventh aspects of the present invention, the efficiency of heat dissipation is improved and high output operation is realized easily by pseudo-constructing the AlGaInP mixed crystal by AlInP having small thermal resistance and GaInP.

Further, according to the sixth and seventh aspects of the present invention, it becomes possible, with the user of the spacer layer of

(Al_aGa_{1-a})_bIn_{1-b}P (0 < a ≤ 1, 0 ≤ b ≤ 1) in the surface-emission laser diode, to increase the bandgap difference between the spacer layer and the quantum well active layer as compared with the case of forming the spacer layer by the AlGaAs system. Thereby, the threshold of laser oscillation is decreased, the efficiency of laser oscillation is improved, and high output operation is realized. Further, by using Ga_cIn_{1-c}P_dAs_{1-d} (0 ≤ c ≤ 1, 0 ≤ d ≤ 1) for the quantum well active layer and by Ga_eIn_{1-e}P_fAs_{1-f} (0 ≤ e ≤ 1, 0 ≤ f ≤ 1) for the barrier layers, it becomes possible to construct the active layer by a material free from Al, and the active region formed of the quantum well active layer and the adjacent layer becomes Al-free. Thereby, it becomes possible to reduce the incorporation of oxygen, and formation of the non-optical recombination centers is suppressed. Thereby, it becomes possible to realize a surface-emission laser diode of long lifetime. Thus, a high output power surface-emission laser diode of the wavelength of 850nm or shorter and having a large gain for the active layer, low threshold value of laser oscillation and good reliability is realized.

Further, according to the surface-emission laser diode of the sixth and seventh aspects of the

present invention, it is possible to reduce the threshold value of laser oscillation by the effect of strain, by using the compressive strain composition for the quantum well active layer, and the efficiency of laser oscillation is improved. Further, as a result of improvement of the carrier confinement efficiency and increase of the gain attained by the use of the strained quantum well active layer, the threshold of laser oscillation is decreased further, and it becomes possible to reduce the reflectivity of the exit-side DBR. With this, it becomes possible to increase the laser output further.

Further, according to the sixth and seventh aspects, it becomes possible to increase the degree of freedom of design such as use of the quantum well active layer of larger strain, by compensating for the strain of the quantum well active layer in the surface-emission laser diode. Further, because the material of the smaller lattice constant has a larger bandgap in the semiconductor material of the GaInPAs system and used for the barrier layer, it becomes possible to increase the band discontinuity to the quantum well active layer. Thereby, the gain is increased and it becomes possible to carry out low-threshold value operation and high output power

operation.

Further, according to the surface-emission laser diode of the seventh aspect, it becomes possible, by constructing the lower reflector such
5 that the lower reflector includes AlAs having small thermal resistance for the low refractive index layers, the dissipation characteristics of heat generated in the active layer are improved, and the temperature rise at the time of driving is
10 suppressed. Thus, a high output power surface-emission laser diode of excellent temperature characteristics is obtained.

Further, according to the surface-emission laser diode of the seventh aspect of the present
15 invention, junction of the AlGaInP system material and the AlGaAs system material is made easily by interposing an intermediate layer of small Al content between the low refractive index layer and the high refractive index layer of the semiconductor
20 distributed Bragg reflector. Thus, in the case of laminating the $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y, x \leq 1$) high refractive index layer on the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1, 0 \leq b \leq 1$) low refractive index layer, it becomes possible to
25 conduct the growth of the high refractive index layer in a wide conditional range by reducing the Al

content at the interface. Further, with such a construction, the band discontinuity of the valence band is decreased and the resistance against the current flowing in the stacked direction is reduced.

5 Further, according to the surface-emission laser diode of the sixth and seventh aspects, it becomes possible, as a result of the use of the AlGaInP system spacer layer, it becomes possible to realize the carrier confinement equivalent to or
10 superior to the case of the surface-emission laser diode of the 780nm band that uses the active layer of the AlGaAs system, even in the case of using the Al-free active layer (quantum well layer and barrier layer), as long as the compositional wavelength is
15 680nm or longer.

 Further, according the surface-emission laser diode of the fourth through seventh aspects of the present invention, it becomes possible to reduce the adversary effects to the device characteristics
20 of the semiconductor layer, such as decrease of bandgap caused by formation of natural super lattices or deterioration of surface morphology or formation of non-optical recombination centers caused by hillock (hill-like defect), by using the (100) GaAs
25 substrate having a surface orientation inclined in

the direction of a (111)A surface with an angle in the range from 5° to 20°. Further, it becomes possible to conduct polarization control by utilizing the nature of the anisotropic substrate. Thus, with
5 the surface-emission laser diode according to the present invention, it is not possible to attain the polarization control as in the case of using the (311)B substrate, which is currently thought most promising, and the anisotropy of optical gain
10 attained with the use of inclined substrate becomes inevitably small, the surface-emission laser diode according to the present invention can successfully compensate for the foregoing decrease of anisotropy of optical gain by providing a compressive strain to
15 the quantum well active layer and induce increase of anisotropy of the optical gain. Thereby, it becomes possible to improve the controllability of the polarization direction with such a surface-emission laser diode.

20 Further, according to the surface-emission laser diode of the first through seventh aspects, it becomes possible to improve the controllability of the polarization direction, by providing anisotropy to the peripheral shape of the active layer as viewed
25 from the optical exit direction of the surface-

emission laser diode such that there is formed a shape elongated in the (111)A direction, such that the effect of increase of the optical gain in the inclined direction of the substrate ((111)A surface direction) is added.

Further, by forming the surface-emission layer diode according to the first through seventh aspects on the same substrate in plural numbers, it is possible to construct a surface-emission laser diode array. Thus, according to the present invention, precision and controllability of mesa formation are improved, and it becomes possible to produce the surface-emission laser diode array having uniform laser characteristics and good processing reproducibility, with high yield and low cost.

Particularly, with the use of the surface-emission laser diode according to the first aspect of the present invention, thermal interference between the elements in the array is suppressed because of the improvement of the heat dissipation characteristics, and it becomes possible to form a high-density array in which the surface-emission laser diode elements are disposed with closer distance from each other.

Further, by applying the construction of

integrating a large number of surface-emission laser diodes of the first through seventh aspects of the present invention, capable of performing high output power operation, on the same substrate for the image
5 writing optical system of an electron photographic image forming apparatus, it becomes possible to achieve high-speed writing by using plural beams at the same time, and the writing speed is improved significantly. Thereby, it becomes possible to carry
10 out printing without decreasing the speed even in the case the density of the writing dots is increased. Further, when compared at the same dot density, the image forming apparatus that uses such a surface-emission laser diode enables printing at higher speed
15 as compared with the conventional image forming apparatuses. Further, when the surface-emission laser diode of the present invention is applied to communication, the data transmission is made by a large number of beams simultaneously, and high-speed
20 communication is realized.

Further, the surface-emission laser diode operates at low power consumption, and thus, it becomes possible, when operated in the state of being incorporated into an apparatus, to reduce the
25 temperature rise in the apparatus.

Further, by using the high output power surface-emission laser diode according to the first through seventh aspects of the present invention or the surface-emission laser diode array of these for the writing optical source, it becomes possible to improve the printing speed as compared with the image forming apparatus that uses a conventional surface-emission laser diode.

Alternatively, in the case of printing at the conventional speed, it becomes possible to reduce the number of the laser arrays, and the yield of production of the surface-emission laser diode array chip is improved significantly. Further, it becomes possible to reduce the cost of the image forming apparatus. In the case the surface-emission laser diode capable of controlling the polarization plane is used, reliability of image formation is improved. Further, in the case a surface-emission laser diode free from Al in the active layer structural part formed of a quantum well active layer and a spacer layer is used, lifetime comparable to the surface-emission laser diode for telecommunication purposes such as the surface-emission laser diode of the 850nm band is attained, and thus, it becomes possible to reuse the optical writing optical unit. Thereby, the

load to the environment is reduced.

Further, by using the surface-emission laser diode according to the first through seventh aspects of the present invention or the surface-emission laser diode array that uses such surface-emission laser diodes for the optical source of optical pickup, it becomes possible to realize a handy type optical pickup system of long battery life. In conventional compact disk devices, a semiconductor layer of 780nm wavelength is used for the optical writing and playback of recording medium, wherein a surface-emission laser diode has power consumption smaller than that of an edge-emission laser diode by a factor of 1/10.

Further, by using the surface-emission laser diode of the first through seventh aspects or the surface-emission laser diode array of such surface-emission laser diodes for the high-power optical source of optical transmission module or optical transceiver module, it becomes possible to construct an economical high-speed optical transmission system that uses a low cost POF (plastic optical fiber).

With the optical transmission that uses an acrylic POF, a surface-emission laser diode of the

oscillation wavelength of 650nm has been used conventionally for the optical source in view of the absorption loss characteristics of the optical fiber, while the use of the surface-emission laser diode in practical purposes is not been successful. Because of this, LEDs are used currently, while an LED is difficult to perform high-speed modulation, and it is indispensable to provide a laser diode in order to realize high-speed transmission exceeding 1Gbps.

10 With the surface-emission laser diode of the present invention having the wavelength of 680nm or longer, a large gain is attained for the active layer and it is possible to provide a large output. Further, the surface-emission laser diode of the present invention has excellent high temperature characteristics. Thus, by using such a surface-emission laser diode, it is possible to achieve, in spite of the fact there is an increase of absorption loss by the fiber, optical transmission of short range. Thus, an economical high-speed optical transmission module or an optical transceiver module that combines a low cost POF with a low cost optical source of surface-emission laser diode is realized. Further, an optical communication system that uses these is realized. Because such an optical

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communicating system is extremely economical, it is suited for the optical communication systems of home use, or for use in office rooms, or for the use inside an apparatus.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram showing a construction example of a general surface-emission laser diode.

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Figure 2 is a diagram showing the fundamental construction example of a surface-emission laser diode of a first mode.

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Figure 3 is a diagram showing the construction of a surface-emission laser diode of Example 1.

Figure 4 is a diagram showing the time-change of atomic emission intensity of In(451nm)/Al(396nm) ratio of Example 1.

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Figure 5 is a diagram showing the construction of a surface-emission laser diode of Example 5.

Figure 6 is a diagram showing the surface-emission laser diode of Example 6.

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Figure 7 is a drawing showing the surface-emission laser diode of Example 6.

Figure 8 is a top view diagram showing the surface-emission laser diode of Example 7.

Figure 9 is a diagram showing the surface-emission laser diode of Example 8.

5 Figure 10 is a diagram showing a surface-emission laser diode array of Example 9.

Figure 11 is a diagram showing an optical transmission module according to Example 10.

10 Figure 12 is a diagram showing an optical transmission/reception module according to Example 11.

Figure 13 is a diagram showing a laser printer of according to Example 12.

15 Figure 14 is a diagram (top view) showing the outline construction of a surface-emission laser diode array chip (16 beam VCSEL array) used in the laser printer of Figure 13.

Figure 15 is a cross-sectional diagram showing, in principle, a part of a first construction example according to a twelfth mode of the present invention.

25 Figure 16 is a cross-sectional diagram showing, in principle, a part of a second construction example of the twelfth mode of the present invention.

Figure 17 is a cross-sectional diagram showing, in principle, a construction example according to a thirteenth mode of the present invention.

5 Figure 18 is a cross-sectional diagram extracting and showing a structure in the vicinity of the active layer of Figure 17 with enlarged scale.

Figure 19 is a plan view diagram of Figure 17.

10 Figure 20 is a cross-sectional view extracting and showing a structure in the vicinity of the active layer according to a fourteenth mode of the present invention with enlarged scale.

Figure 21 is a diagram showing the
15 construction example of the peripheral part of the active layer of the surface-emission laser diode for the case an AlGaInP layer is provided in a cavity region sandwiched by the upper and lower reflectors in a seventeenth and eighteenth modes.

20 Figure 22 is a diagram showing a construction example of the surface-emission laser diode according to a twenty-first mode of the present invention.

BEST MODE FOR IMPLEMENTING THE INVENTION

25 Hereinafter, various modes of the present

invention will be explained with reference to the drawings.

(FIRST MODE)

According to a first mode of the present
5 invention, there is provided a surface-emission laser diode, comprising:

a semiconductor substrate;

a cavity region formed over said
semiconductor substrate, said cavity region
10 comprising an active layer structural part including at least one quantum well active layer producing a laser light and barrier layers, and a spacer layer provided in a vicinity of said active layer structural part, said spacer layer comprising at
15 least one material; and

an upper reflector and a lower reflector provided over said semiconductor substrate at a top part and a bottom part of said cavity region,

said cavity region, said upper reflector
20 and said lower reflector forming a mesa structure over said semiconductor substrate,

said upper reflector and said lower reflector constituting a semiconductor distributed Bragg reflector having a periodic change of
25 refractive index and reflecting an incident light by

interference of optical waves,

at least a part of said semiconductor distributed Bragg reflector being formed of a layer of small refractive index of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) and a
5 layer of large refractive index of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$),

said lower reflector being formed of a first lower reflector having a low-refractive index layer of AlAs and a second lower reflector formed on
10 said first lower reflector, said second lower reflector having a low-refractive index layer of AlGaAs,

wherein any one layer constituting said cavity region contains In.

15 With this first mode of the present invention, any one layer constituting the cavity region contains In, and the lower semiconductor DBR contains an AlAs/(Al)GaAs-DBR having excellent heat dissipation characteristic. Thus, the precision and
20 reproducibility of mesa formation is improved, and it becomes possible to provide the AlAs/(Al)GaAs-DBR to the region close to the cavity region.

With this, temperature rise at the time of driving is suppressed, and a high output power
25 surface-emission laser diode having excellent

temperature characteristics is provided. At the same time, a surface-emission laser diode having highly uniform laser characteristics, excellent reproducibility for processing and excellent yield is
5 provided.

With the surface-emission laser diode of the first mode, it is possible to introduce In to at least the lower spacer layer and the upper spacer layer among the layers constituting the cavity
10 region.

According to such a construction in which In is contained in the spacer layer having much larger thickness than the active layer structural part among the layers constituting the cavity region,
15 it becomes possible to form the mesa structure with further improved reproducibility and further improved precision, and with this, it becomes possible to obtain a surface-emission laser diode of further improved temperature characteristics, higher output
20 power and further improved uniformity in laser characteristics, with higher reproducibility of processing and with higher yield.

Further, it is preferable that the second lower reflector of the surface-emission laser diode
25 according to the mode of the present invention

includes 10 pairs or less.

With such a construction, the thickness of the second lower semiconductor DBR is set to be larger than the precision of the mesa etching and at
5 the same time minimum. With this, it becomes possible to produce the surface-emission laser diode with improved yield.

Further, the surface emission laser diode of the first mode of the present invention can be
10 fabricated by: forming, on a semiconductor substrate, a cavity region comprising an active layer structural part including at least one quantum well active layer producing a laser light and a barrier layer; and forming a spacer layer of at least one material so as
15 to be provided in a vicinity of said active layer structural part to form of a stacked film, such that, in the stacked film, an upper reflector and a lower reflector are provided at a top part and a bottom part of said cavity region, and processing the
20 stacked film by a dry etching process to form a mesa structure. Thereby, with the present mode, In is incorporated to any one layer constituting said cavity region, and the height of said mesa structure is controlled by monitoring light emission of In in
25 the dry etching step.

According to the fabrication process of the foregoing mode, the height of the mesa structure is controlled in the step of forming the mesa structure by the dry etching of the stacked film, by monitoring
5 the light emission of In. Because the dry etching is conducted while monitoring the light emission of In from the cavity layer, it is possible to detect the cavity layer positively, and with this, it becomes possible to form the mesa structure with high
10 reproducibility and high precision. As a result, it becomes possible with the present mode to produce the first surface-emission laser diode with high reproducibility and yield.

Figure 2 shows the fundamental construction
15 of a surface-emission laser diode 40 according to the first mode of the present invention.

Referring to Figure 2, the surface-emission laser diode 40 has a VCSEL stacked structure formed of consecutive lamination of: a first lower
20 semiconductor DBR 42 of $\text{AlAs}/\text{Al}_{1-u}\text{Ga}_u\text{As}$ ($0 < u \leq 1$) formed on a monocrystalline semiconductor substrate 41 of GaAs, InP, GaP, GaNAs, Si, Ge, or the like, directly or via an intermediate layer by way of an MOCVD process or an MBE process; a second lower DBR 43 of
25 $\text{Al}_{1-v}\text{Ga}_v\text{As}/\text{Al}_{1-w}\text{Ga}_w\text{As}$ ($0 < v < 1$, $0 < w \leq 1$, $v < w$); a cavity

layer 44 of a lower spacer layer 44A, an active layer 44B, and an upper spacer layer 44C, the cavity layer 44 containing In in any one layer of the lower spacer layer 44A, the active layer 44B and the upper spacer layer 44C; a selective oxidation layer 45 of $\text{Al}_{1-t}\text{Ga}_t\text{As}$ ($0 \leq t \leq 0.05$); and an $\text{Al}_{1-v}\text{Ga}_v\text{As}/\text{Al}_{1-w}\text{Ga}_w\text{As}$ ($0 < v < 1, 0 < w \leq 1, v < w$) upper DBR 46.

Here, it should be noted that the layer containing In is formed of a compound semiconductor material represented as $\text{Al}_{1-x-y}\text{Ga}_x\text{In}_y\text{As}_{1-z}\text{P}_z$ ($0 \leq x \leq 1, 0 < y \leq 1, 0 < (x+y) \leq 1, 0 \leq z \leq 1$), and typically formed of GaInP, GaInAsP, GaInAs, AlGaInAs, AlGaInAsP, wherein the layer may further contain other group III or group V element such as B, N, Sb, Tl, or the like.

Table 1 represents examples of such a VCSEL stacked structure.

Table I

	Wave-length Band (nm)	Quantum Well Active Layer (well/barrier)	Upper/lower Spacer Layer
Ex1	650	InGaP/AlGaInP	$(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$
Ex2	780	GaInAsP/AlGaInP	$(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$
Ex3	850	GaAs/InGaAsP	$\text{In}_{0.27}\text{Ga}_{0.73}\text{As}_{0.44}\text{P}_{0.56}$
Ex4	980	GaInAs/GaAs	GaIn(As)P
Ex5	1300	GaInNAs/GaAs	GaIn(As)P

Table I (continued)

	Upper Semiconductor DBR
Ex1	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$
Ex2	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$
Ex3	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$

Ex4	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{GaAs}$
Ex5	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{GaAs}$

Table I (Continued)

	Wave-length Band (nm)	First Lower Semiconductor DBR	Second Lower Semiconductor DBR
Ex1	650	$\text{AlAs}/\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$
Ex2	780	$\text{AlAs}/\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$
Ex3	850	$\text{AlAs}/\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$
Ex4	980	AlAs/GaAs	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{GaAs}$
Ex5	1300	AlAs/GaAs	$\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{GaAs}$

Next, a mesa mask pattern is formed by a photoresist, or the like, and the stacked structure thus formed is held in a processing vessel of a dry etching apparatus. Further, a halogen gas such as Cl_2 , BCl_3 , SiCl_4 , CCl_4 , CF_4 , or the like, is introduced into the processing vessel, and a mesa etching is conducted by a dry etching process that uses plasma such as reactive ion beam etching (RIBE) method, induction coupled plasma (ICP) etching method, reactive ion etching method (RIE), or the like.

During such mesa etching process, plasma atomic emission spectrometry is conducted via an observation window provided to the processing vessel of the dry etching apparatus, and the time change of emission intensity of In at the wavelength of 451nm is monitored. With the present invention, the atomic

emission of In is detected only when the cavity region is etched, and thus, it becomes possible to stop the etching positively while the etching is in progress inside the second semiconductor DBR 43.

5 Next, the Al(Ga)As layer for selective oxidation 45 is processed in water vapor, and a current confinement structure of Al_xO_y is formed. Next, the space surrounding the mesa structure thus formed is filled with an insulation film 47 of
10 polyimide or SiO_2 except for the part where electrode is to be provided and the part used for optical output. By forming the insulation film 47, the surface-emission laser element is planarized.

 Further, a p-side electrode 48 and an n-
15 side electrode 49 are formed at respective locations, and fabrication of the surface-emission laser diode 40 of Figure 2 is completed.

 With the surface-emission laser diode 40, positive carriers and negative carriers are injected
20 respectively from the p-side electrode 48 and the n-side electrode 49, and there are caused photoemission in the active layer 44B. With this, it becomes possible to obtain a laser light in the vertical direction to the substrate 41. While Figure 2 shows
25 the construction that provides an optical output in

the upward direction of the substrate 41, it is also possible to construct such that optical output is obtained in the downward direction of the substrate 41.

5 Here, it should be noted that all of the lower spacer layer 44A, the active layer 44B, and the upper spacer layer 44C constitutes the cavity 44, and the thickness of the cavity, defined as a sum of these, becomes $(N_0+1) \times \lambda/n$. In many cases, the cavity
10 thickness is λ/n . Here, N_0 is an integer of 0 or larger, λ is the oscillation wavelength, and n is the refractive index of the semiconductor constituting the cavity 44.

 Further, because the active layer 44B is
15 usually implemented in the form of thin quantum well structure, the majority of the cavity length is occupied by the upper and lower spacer layers 44A and 44C. Further, the thickness of the semiconductor DBR
43 is $(1+2 \times N_0) \times \lambda/(4 \times n)$. In many cases, it is $\lambda/(4 \times n)$.
20 Thus, the upper and lower spacer layers 44A and 44C have a thickness much larger than any other films in the stacked structure.

 From this, strong photoemission of In is achieved at the time of the etching in the case the
25 upper and lower spacer layers 44A and 44C contains

In, and it becomes possible to control the endpoint of etching with high precision. With this, the reproducibility of the mesa etching is improved significantly.

5 Further, it becomes possible to control the variation of the etching depth, when the foregoing VSCEL stacked structure is etched on a single wafer by using the foregoing monitoring method, such that the bottom of the mesa structure is located within
10 the range of 2 or 3 pairs of the foregoing second lower semiconductor DBR 43. Thus, even when variation of mesa height within the wafer is taken into consideration, or variation between the wafers when a large number of wafers are etched simultaneously is
15 taken into consideration, it is possible to achieve the necessary etching control by using ordinary etching process, provided that there are only ten repetitions in the maximum for the high refractive index layer and the low refractive index layer in the
20 second lower semiconductor DBR 43.

 Thus, according to the present mode, it becomes possible to use the construction in which the AlAs/(Al)GaAs-DBR43 of small thermal resistance is provided to the vicinity of the cavity of the
25 surface-emission laser diode. Thereby, the efficiency

of heat dissipation is improved and the temperature rise at the time of driving is suppressed, and a high output power surface-emission laser diode of excellent temperature characteristics is obtained.

5 In the case of using the material or thickness in which the oxidation rate of the low refractive index layer in the first lower semiconductor DBR 42 is larger than the oxidation rate of the selectively oxidized semiconductor layer 10 45, the mesa etching should not reach the first lower semiconductor DBR 42. Such a situation is not limited to the case in which the selective oxidized layer 45 and the low refractive index layer of the first lower semiconductor DBR 42 are both formed of AlAs. For 15 example, there can be a case in which the layer for selective oxidation 45 is not AlAs but contains a small amount of Ga and the low refractive index layer of the first lower semiconductor DBR is not AlAs but also contains Ga.

20 Even in such cases, however, satisfactory heat dissipation effect is attained as long as the low refractive index layer of the second lower semiconductor DBR 43 is formed of the material having the oxidation rate smaller than the oxidation rate of 25 the layer for selective oxidation 45 and when the low

refractive index layer of the first lower
semiconductor DBR 42 is of the composition or
material in which the thermal resistance is smaller
than the low refractive index layer of the second
5 layer semiconductor DBR 43.

Further, in addition to the method of
simply monitoring the photo emission intensity of In,
it is also possible, with the emission spectrometry
of In, to monitor the ratio of the emission intensity
10 of In to the emission intensity of other constituent
element, or the ratio of the emission intensity of In
to the emission intensity of the wavelength different
from any of the foregoing, so as to cancel out the
effect of variation of the plasma state.

15 In order to control the etching bottom to
be right underneath the cavity, it is also possible
to use GaInP or AlGaInP for the uppermost layer of
the lower semiconductor DBR 43 and use GaAs or AlGaAs
for the upper layer that includes the cavity. With
20 such a case, it becomes possible to conduct selective
oxidation by using a $\text{H}_2\text{SO}_4/\text{H}_2\text{O}_2/\text{H}_2\text{O}$ solution. However,
with such a wet etching process, control of the mesa
width is difficult, and there tends to arise the
problems in that, because of etching anisotropy,
25 there is formed a mesa of asymmetric shape. In view

of the foregoing situations, it is preferable to conduct the mesa etching by a dry etching process.

With the foregoing construction, it should be noted that, while the AlAs selective oxidized layer 45 is provided in the vicinity of the active layer 44B, the location is not limited, in view of the cases in which it is provided inside the DBR as the low refractive index layer of the upper semiconductor DBR 46 or the low refractive index layer of the lower semiconductor DBRs 42 and 43.

Further, while explanation has been made for the case in which In is contained only in the cavity region 44, all what is required is that the situation of the etching of the cavity region 44 is grasped and that the etching does not reach the first lower reflector 42, and thus, it is also possible to provide a layer containing In other than the cavity region, such as a part of the reflector 43 closest to the cavity region 44.

(SECOND MODE)

According to a second mode, there is provided a surface emission laser diode, in which a part of the spacer layers 44A and 44C is formed of $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) in the surface-emission laser diode 40 of the first mode and the

active layer 44B is formed of a quantum well layer of $\text{Ga}_c\text{In}_{1-c}\text{P}_d\text{As}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$) and a barrier layer of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$).

By using $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) for a part of the spacer layers 44A and 44C, it becomes possible to increase the bandgap difference between the spacer layer and the quantum well active layer as compared with the case of forming the spacer layer by the AlGaAs system.

Table 2 shows the bandgap difference caused between the spacer layer and the quantum well layer and between the barrier layer and the quantum well layer for the typical material compositions used in the surface-emission layer diode of the 780nm and 850nm wavelengths that uses the AlGaAs (spacer)/AlGaAs (quantum well active layer) system and further in the surface-emission laser diode of the 780nm wavelength band that uses the AlGaInP (spacer) layer)/GaInPAs (quantum well active layer).

TABLE 2

Wavelength		780nm
		Spacer layer/quantum well active layer AlGaAs/AlGaAs system material
Spacer layer		$\text{Al}_{0.6}\text{Ga}_{0.4}\text{As}$ ($E_g=2.0226\text{eV}$)
Active layer	Quantum well active layer	$\text{Al}_{0.12}\text{Ga}_{0.88}\text{As}$ ($E_g=1.5567\text{eV}$)
	Barrier	$\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$

	layer	(Eg=1.7755eV)
Eg difference (ΔE_g) between spacer layer and quantum well layer		465.9meV
Eg difference (ΔE_g) between barrier layer and quantum well layer		218.8meV

TABLE 2 (Continued)

Wavelength		780nm
		AlGaInP/GaInPAs system material
Spacer layer		(Al _x Ga _{1-x}) _{0.5} In _{0.5} P (Eg (x=0.7)=2.289eV)
Active layer	Quantum well active layer	GaInPAs (compressive strain) (Eg=1.5567eV)
	Barrier layer	Ga _x In _{1-x} P (tensile strain) (Eg (x=0.6)=2.02eV)
Eg difference (ΔE_g) between spacer layer and quantum well layer		743.3meV
Eg difference (ΔE_g) between barrier layer and quantum well layer		463.3meV

TABLE 2 (Continued)

Wavelength		850nm (Ref.)
		AlGaAs/GaAs system material
Spacer layer		Al _{0.6} Ga _{0.4} As (Eg=2.0226eV)
Active layer	Quantum well active layer	GaAs (Eg=1.42eV)
	Barrier layer	Al _{0.3} Ga _{0.7} As (Eg=1.7755eV)

Eg difference (ΔE_g) between spacer layer and quantum well layer	602.6meV
Eg difference (ΔE_g) between barrier layer and quantum well layer	355.5meV

As can be seen in Table 2, it becomes possible to secure a large bandgap difference with the surface-emission laser diode of the 780nm band that uses the AlGaInP (spacer layer)/GaInPAs (quantum well active layer) system as compared with the surface-emission laser diode of the 780nm wavelength band of the AlGaAs/AlGaAs system or the surface-emission laser diode of the 850nm band of the AlGaAs/AlGaAs system.

Further, with the surface-emission laser diode of such a construction, it is possible to use a compressive strain composition for the quantum well active layer. With increase of strain, band splitting between the heavy holes and light holes is increased, while this leads to increase of the gain and decrease of threshold value of laser oscillation. Thereby, the efficiency of laser oscillation is improved and the laser output is increased. It should be noted that this effect is not achieved with the surface-emission

laser diode of the 850nm band that uses the AlGaAs/AlGaAs system.

Thus, according to the surface-emission laser diode of the present invention that uses the AlGaInP/GaInPAs material system, the threshold value is decreased as compared with the surface-emission laser diode of 850nm that uses the AlGaAs/AlGaAs system, and it becomes possible to realize a high output power laser of improved laser oscillation efficiency.

Further, according to the surface-emission laser diode of the second mode, the efficiency of carrier confinement is improved and the threshold value is decreased also by the increase of gain as a result of use of the strained quantum well active layer, and as a result, it becomes possible to reduce the reflectivity of the exit-side DBR. With this, it is possible to attain further increase of the optical output.

Further, with the surface-emission laser diode of the second mode, the quantum well active layer is formed of $\text{Ga}_c\text{In}_{1-c}\text{P}_d\text{As}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$) and the barrier layer is formed of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$), while it should be noted that this material is free from Al, and thus, incorporation of oxygen

into the quantum well active layer is reduced because of the fact that the active layer structural part 44, formed of the quantum well active layer and the layer adjacent thereto, is free from Al. Thereby, formation
5 of non-optical recombination center can be suppressed and it becomes possible to realize a surface-emission laser diode of long lifetime.

Thus, by using AlGaInP material for a part of the spacer layers 44A and 44C and by using GaInPAs
10 for the barrier layer or quantum well active layer, the optical gain of the active layer is increased, and it becomes possible to realize a reliable high output power surface-emission laser diode that has a low threshold value and oscillates at the wavelength
15 band shorter than 850nm.

In order to attain the foregoing effect, it is preferable to consider the surface orientation of the substrate 41 as explained below.

In the surface-emission laser diode that
20 uses AlGaInP or GaInP for the active region, in particular, it is preferable to use a (100) GaAs substrate having a surface orientation inclined in the direction of a (111)A surface by an angle (inclination angle) of the range of 5° to 20° for the
25 substrate 41. The reason of this is that, when the

surface orientation of the substrate is close to (100), there is caused problems such as decrease of bandgap by formation of natural superlattices, deterioration of surface morphology caused by hillock
5 (hill-like defect), formation of non-optical recombination centers, and the like, and there is a possibility that the device characteristics of the laser diode formed on the substrate is adversely affected.

10 When the surface orientation of the substrate is inclined from (100) surface to the direction of (111)A surface, formation of the natural superlattice is suppressed in correspondence to the inclination angle. Thus, the bandgap changes sharply
15 in the range of the inclination angle of 10° to 15° , and thereafter, the band gap approaches the nominal bandgap (bandgap value of the mixed crystal). Further, formation of hillocks is gradually suppressed.

20 On the other hand, when the inclination angle in the direction of (111)A surface exceeds 20° , crystal growth on the substrate becomes difficult. Thus, with the red color laser (630nm to 680nm) that uses the AlGaInP material, the substrate inclined to
25 the angle in the range of 5° to 20° (in many cases in

the range of 7° to 15°) is used commonly. This applies not only to the case AlGaInP is used for the spacer layer (cladding layer), but also to the case in which GaInP is used for the barrier layer as in the example of Table 2. Further, in anticipation of adversary effect caused also in the case the barrier layer and the quantum well active layer are formed of GaInPAs, it is preferable to use a (100) GaAs substrate having a surface orientation inclined in the direction of (111)A surface with the angle in the range of 5° to 20° (more preferably with the angle in the range of 7° to 15°), for the growth of these materials.

On the other hand, in the case the surface orientation of the substrate 41 is inclined in the direction of (111)A surface, it is not possible to use the control technology of polarization angle (polarization direction) that uses the optical gain anisotropy of (311)B substrate and thought as being most promising technology at the current juncture. Thus, while the present mode can suppress the cost of the substrate by using an inclination angle (range of 5° to 20°) smaller than the (311)B substrate (inclination angle of 25°) and that cleaving is made easily and handling of the substrate becomes easier,

the optical gain anisotropy that can be obtained becomes inevitably small.

Thus, the present mode compensates for the decrease of the optical gain anisotropy by the
5 increase of the optical gain anisotropy induced by applying a compressive strain to the quantum well active layer.

It should be noted that, while the foregoing example limits the wavelength to be shorter
10 than 850nm, this is merely because a very large advantage is obtained with this wavelength range, and similar effect is obtained also in the wavelength longer than 850nm.

Thus, with the present mode, a surface-
15 emission laser diode of high output power and excellent reliability is obtained such that the surface laser diode operates at the wavelength of 850nm or shorter and has the feature of, in addition to the features of the first mode of large gain for
20 the active layer and reduced threshold value, controlled polarization direction.

(THIRD MODE)

According to a third mode, there is provided a surface-emission laser diode, comprising:
25 a (100) GaAs substrate having a surface orientation

inclined in a direction of a (111)A surface by an angle of 5° to 20° ; a cavity region provided over said GaAs substrate, said cavity region including an active layer structural part comprising at least one
5 layer of quantum well active layer producing a laser light and barrier layers, and a spacer layer provided in a vicinity of said active layer structural part, said spacer layer comprising at least one material; and an upper reflector and a lower reflector provided
10 at a top part and a bottom part of said cavity region, said cavity region and said upper and lower reflectors forming a mesa structure over said GaAs substrate, said upper reflector and said lower reflector comprising a semiconductor distributed
15 Bragg reflector having a periodic change of refractive index and reflecting an incident light by interference of optical waves, at least a part of said semiconductor distributed Bragg reflector being formed of a layer of small refractive index of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) and a layer of large refractive index of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$), a part of said spacer layer
20 comprising $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$), said quantum well active layer comprising $\text{Ga}_c\text{In}_{1-c}\text{PdAs}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$), said barrier layers comprising $\text{Ga}_e\text{In}_{1-e}\text{PdAs}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$), said quantum well active
25

layer having a compressive strain, said active layer structural part having a shape anisotropy elongated in a direction of a (111)A surface as viewed from a direction of light emission.

5 When controlling the polarization angle (polarization direction) by using the optical gain anisotropy caused by inclining the surface orientation of the substrate in the direction of (111)A surface with the surface emission laser diode
10 of the present invention, it is not possible to utilize the effect of the (311)B substrate, which is thought as being most promising at the current juncture, because of the use of the inclination angle (range of 5° to 20°), which is smaller than the
15 (311)B substrate (inclination angle of 25°).

 Thus, with the third mode of the present invention, this decrease is compensated for by the increase of the optical gain anisotropy obtained by applying a compressive strain to the quantum well
20 active layer, and further by providing anisotropy to the outer shape of the active layer as viewed from the direction of optical emission of the surface-emission laser diode, such that the optical gain in the inclined direction ((111)A surface direction) of
25 the substrate is increased by providing an elongated

shape in the direction of (111)A surface to the active layer. With this, the optical gain in the direction of the inclination angle (direction of (111)A surface) is increased further and
5 controllability of the deflection angle is improved.

(FOURTH MODE)

A fourth mode of the present invention provides a surface-emission laser diode of the second
10 or third mode in which the barrier layer has a tensile strain.

In the material of the GaInPAs system used for the barrier layer of the quantum well active layer in the surface-emission laser diode, GaInP has
15 the largest bandgap when compared with the same lattice constant. Further, a larger bandgap is obtained with the material having a smaller lattice constant. Thus, by using a material of the GaInP system of small lattice constant for the barrier
20 layer, it is possible to realize a large band discontinuity between the barrier layer and the quantum well active layer, and it becomes possible to increase the gain of the surface-emission laser diode. With this, the surface-emission laser diode
25 can perform high output power operation with low

threshold value. For example, it should be noted that the bandgap of the tensile-strained $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ layer is 2.02eV, the bandgap of the $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ lattice matched layer is 1.87eV, and thus the $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ tensile strain layer has a bandgap larger by 150meV.

(FIFTH MODE)

With the fifth mode of the present invention, there is provided a surface-emission laser diode of any of the second through fourth modes in which the oscillation wavelength is about 680nm or longer.

Comparing the surface-emission laser diode of the present mode with the surface-emission laser diode of 780nm that uses the active layer of the $\text{AlGaAs}/\text{AlGaAs}$ system, it can be seen that the bandgap difference between the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.6$, $E_g=2.0226\text{eV}$), which provides the largest bandgap in the typical compositional range of the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) system spacer layer used with the surface-emission laser diode of the $\text{AlGaAs}/\text{AlGaAs}$ system, and the active layer of the compositional wavelength of 780nm ($E_g=1.5567\text{eV}$) is generally equal to the bandgap difference (460meV) between $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($a=0.7$, $b=0.5$, $E_g=2.289\text{eV}$), which provides the largest

bandgap in the typical compositional range of the
(Al_aGa_{1-a})_bIn_{1-b}P (0<a≤1, 0≤b≤1) spacer layer used with
the surface emission laser diode of the present mode
and the active layer of the compositional wavelength
5 of 680nm (E_g=1.8233eV).

Further, with regard to the bandgap
difference between the barrier layer and the quantum
well active layer, it should be noted that the
bandgap difference to the active layer of the
10 compositional wavelength of 680nm becomes about
200meV, assuming that the barrier layer has the
composition Ga_eIn_{1-e}P_fAs_{1-f} (e=0.6, f=1, E_g=2.02eV),
while this is generally equal to the case of the
780nm surface-emission laser diode of the active
15 layer of the AlGaAs/AlGaAs system.

This means, that by using the spacer layer
of the AlGaInP system, it becomes possible to achieve
the carrier confinement equivalent or larger than the
surface-emission laser diode of 780nm that uses the
20 AlGaAs/AlGaAs system active layer, even in the case
the surface-emission laser diode is the one that uses
the Al-free active layer (quantum well active layer
and the barrier layer), as long as the compositional
wavelength is longer than 680nm. In practice, the
25 characteristics equivalent or more are attained in

view of the effect of the strained quantum well active layer.

(SIXTH MODE)

According to the sixth mode, there is
5 provided a surface-emission laser diode array in which plural surface-emission laser diodes of any of the first through fifth modes are constructed on a common substrate.

Generally, a surface-emission laser diode
10 can easily construct a laser array in view of its surface-emission construction. Further, because each surface-emission laser diode element is formed with an ordinary semiconductor process, it is possible to form the individual surface-emission laser diode
15 elements with high positional precision.

Particularly, according to the present invention, controllability of etching at the time of mesa formation is improved, and as a result, there is attained an improvement of yield, and it becomes
20 possible to reduce the production cost.

Further, according to the present invention, heat dissipation efficiency of the lower DBR is improved, and as a result, thermal interference between the elements in the array is
25 reduced, and it becomes possible to increase the

output of the individual devices and increase the formation density of the elements.

Further, by using the laser array in which a large number of high output power surface-emission laser diodes of the present invention, each having a polarization direction controlled in a predetermined direction, are integrated on a common substrate, it becomes possible to realize simultaneous writing by plural beams in a writing optical system of image forming apparatus, or the like, and the writing speed is improved significantly. Further, according to such a construction, it becomes possible to conduct printing without decreasing the printing speed even in the case the writing dot density is increased. In the same context, it is possible to increase the printing speed when the writing dot density is held constant. When such a laser array is applied to communication, it becomes possible to carry out simultaneous data transmission with plural beams, and high speed communicating becomes possible. Further, because the surface-emission laser diode operates with low power consumption, it becomes possible to suppress the temperature rise inside an apparatus when the laser diode is assembled into the apparatus.

(SEVENTH MODE)

According to a seventh mode of the present invention, there is provided an image forming apparatus that uses the surface-emission laser diode of any of the first through fifth modes or the
5 surface-emission laser diode array of the sixth mode for the writing optical source.

Because the surface-emission laser diode or the surface-emission laser diode array of the present invention has a controlled polarization direction and
10 operates with high output power, the image forming apparatus of the present embodiment is capable of performing high speed printing as compared with the image forming apparatus that uses a conventional surface-emission laser diode array. In the case the
15 image forming apparatus is designed to provide a conventional printing speed, on the other hand, it becomes possible to reduce the number of the laser arrays used. Thereby, the yield of production of the surface-emission laser diode array chip is improved
20 significantly, and the production cost of the image forming apparatus can be reduced. Further, because the surface-emission laser diode of the present embodiment uses an Al-free active layer for the active layer, it becomes possible to attain the
25 lifetime equivalent to the lifetime (estimated of 100

million hours at room temperature is reported) of
the communication purpose surface-emission laser
diode such as the surface-emission laser diode of the
850nm band, and thus, it becomes possible to reuse
5 the optical unit for optical writing. With this, the
load to the environment can be reduced.

(EIGHTH MODE)

According to an eighth mode of the present
invention, there is provided an optical pickup
10 system that uses the surface-emission laser diode
according to any of the first through fifth modes or
the surface-emission laser diode array of the sixth
mode as the optical source.

Conventionally, a compact disk apparatus
15 uses the wavelength of 780nm for the writing and
playback optical source to an optical media. Because
the surface-emission laser diode has a power
consumption smaller than that of an edge-emission
laser diode by the factor of ten, it becomes possible
20 to realize a handy type optical pickup system
characterized by long battery life, by using the
surface-emission laser diode of the 780nm band for
the playback optical source.

(NINTH MODE)

25 According to a ninth mode, there is

provided an optical transmission module that uses the surface-emission laser diode of any of the first through fifth modes or the surface-emission laser diode array of the sixth mode.

5 With the optical transmission that uses an acrylic POF, a surface-emission laser diode of the oscillation wavelength of 650nm has been used conventionally for the optical source in view of the absorption loss characteristics of the optical fiber,
10 while the use of the surface-emission laser diode in practical purposes is not been successful. Because of this, LEDs are used currently, while an LED is difficult to perform high-speed modulation, and it is indispensable to provide a laser diode in order to
15 realize high-speed transmission exceeding 1Gbps.

 With the surface-emission laser diode of the present invention having the wavelength of 680nm or longer, a large gain is attained for the active layer and it is possible to provide a large output.
20 Further, the surface-emission laser diode of the present invention has excellent high temperature characteristics. Thus, by using such a surface-emission laser diode, it is possible to achieve, in spite of the fact there is an increase of absorption
25 loss by the fiber, optical transmission of short

range. Thus, an economical high-speed optical transmission module that combines a low cost POF with a low cost optical source of surface-emission laser diode is realized.

5 (TENTH MODE)

According to a tenth mode of the present invention, there is provided an optical transceiver module that uses the surface-emission laser diode of any of the first through fifth modes or the surface-
10 emission laser diode array of the sixth mode as an optical source.

With the optical transmission that uses an acrylic POF, a surface-emission laser diode of the oscillation wavelength of 650nm has been used
15 conventionally for the optical source in view of the absorption loss characteristics of the optical fiber, while the use of the surface-emission laser diode in practical purposes is not been successful. Because of this, LEDs are used currently, while an LED is
20 difficult to perform high-speed modulation, and it is indispensable to provide a laser diode in order to realize high-speed transmission exceeding 1Gbps.

With the surface-emission laser diode of the present invention having the wavelength of 680nm
25 or longer, a large gain is attained for the active

layer and it is possible to provide a large output. Further, the surface-emission laser diode of the present invention has excellent high temperature characteristics. Thus, by using such a surface-
5 emission laser diode, it is possible to achieve, in spite of the fact there is an increase of absorption loss by the fiber, optical transmission of short range. Thus, an economical high-speed optical transceiver module that combines a low cost POF with
10 a low cost optical source of surface-emission laser diode is realized.

(ELEVENTH MODE)

According to an optical communication system of the eleventh mode of the present invention,
15 there is provided an optical communication system that uses the surface-emission laser diode according to any of the first through fifth modes or the surface-emission laser diode array of the sixth mode as the optical source.

20 With the optical transmission that uses an acrylic POF, a surface-emission laser diode of the oscillation wavelength of 650nm has been used conventionally for the optical source in view of the absorption loss characteristics of the optical fiber,
25 while the use of the surface-emission laser diode in

practical purposes is not been successful. Because of this, LEDs are used currently, while an LED is difficult to perform high-speed modulation, and it is indispensable to provide a laser diode in order to
5 realize high-speed transmission exceeding 1Gbps.

With the surface-emission laser diode of the present invention having the wavelength of 680nm or longer, a large gain is attained for the active layer and it is possible to provide a large output.
10 Further, the surface-emission laser diode of the present invention has excellent high temperature characteristics. Thus, by using such a surface-emission laser diode, it is possible to achieve, in spite of the fact there is an increase of absorption
15 loss by the fiber, optical transmission of short range. Thus, an economical high-speed optical transceiver module that combines a low cost POF with a low cost optical source of surface-emission laser diode is realized.

20 Because such a system is extremely economical, it is suited for providing an optical communication system used in common homes and in office rooms or in an apparatus.

Hereinafter, examples of the present
25 invention will be explained.

EXAMPLE 1

Figure 3 shows the construction of a surface-emission laser diode 60 according to Example 1 of the present invention. It should be noted that
5 the surface-emission laser diodes of Examples 2, 3 and 4 to be described later have also the construction similar to that of Figure 3.

Referring to Figure 3, Example 1 forms a VCSEL stacked structure on an n-GaAs monocrystal
10 (100) substrate 61 by consecutively stacking, by way of an MOCVD process, a first lower semiconductor DBR 62 in which an n-AlAs/ $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ pair is repeated for 42.5 times, a second lower semiconductor DBR 63 in which an n- $\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ pair is repeated
15 six times, a $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ lower spacer layer 64A, a GaInAsP/ $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ (well/barrier) TQW active layer 64B, a $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ upper spacer layer 64C, a p-AlAs selective oxidation layer 65, an upper semiconductor DBR 66 in which a p- $\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ pair is
20 repeated 34.5 times, and a p-GaAs contact layer 67. Here, the lower spacer layer 64A, the active layer 64B and the upper spacer layer 64C forms a cavity structure 64.

Next, a circular mesa mask is patterned on
25 such a VCSEL stacked structure thus formed by a

photoresist, and mesa etching is started by a reactive ion beam etching (RIBE) method by introducing a Cl_2 gas.

In the present embodiment, the emission
5 intensity of In (451nm) and the emission intensity of Al (396nm) are obtained during the mesa etching process by using a plasma atomic emission spectrometer, and the time change of the ratio (In/Al ratio) is monitored.

10 Figure 4 shows the time change of the In (451nm)/Al(396nm) emission intensity ratio obtained with Example 1.

Referring to Figure 4, it can be seen that emission of In (451nm) is detected after several
15 minutes after the commencement of the etching, while this emission disappears in the meantime. Thus, when the etching is terminated at the moment the emission of In has disappeared, the mesa etching stops at the third layer from the top of the second lower
20 semiconductor DBR 63, and the mesa structure M of Figure 3 is formed.

Next, at the moment the mesa structure M is formed, the AlAs selective oxidation layer 65 is annealed in water vapor ambient at 400°C , and there
25 is formed a current confinement structure inside the

AlAs layer for selective oxidation 65 such that the non-oxidized AlAs region has an area of $25\mu\text{m}^2$.

Further, the surrounding area of the mesa structure is filled with a polyimide protective film 68

5 excluding the part used for electrode contact and the part used for optical exit.

Next, a p-side electrode film 69 is deposited on the top surface of the mesa structure M in contact with the p-type contact layer 67 by an
10 evaporation deposition process, and an opening for optical output is formed by a liftoff process. Further, an n-side electrode 70 is provided on the rear side of the substrate 61 and the surface-emission laser diode of the construction shown in
15 Figure 3 is fabricated.

With the surface-emission laser diode 60 of Example 1, positive carriers and negative carriers are injected respectively from the p-side electrode 69 and the n-side electrode 70, and the laser beam of
20 the wavelength of 780nm is emitted in the direction perpendicular to the substrate 61 via the opening formed in the upper electrode 69.

With the surface-emission laser diode 60 of Example 1, the VCSEL stacked structure containing In
25 in the entirety of the cavity structure 64 is etched

while monitoring the photoemission of In, and it becomes possible to detect the cavity structure 64 conveniently at the time of etching. Thus, it becomes possible to form the second lower semiconductor DBR 5 63 with the number of layers smaller than 4/7 of the total lower semiconductor DBR. As a result, temperature rise of the device is suppressed and it becomes possible to drive the surface-emission laser diode with higher output power. Further, with the 10 present embodiment, mesa etching is conducted with good reproducibility, and the mesa heights become uniform, and it becomes possible to obtain surface-emission laser diodes of uniform laser characteristics with high yield.

15 Example 2

Next, a surface-emission laser diode 80 according to Example 2 of the present invention will be explained. As noted before, the surface-emission laser diode 80 of Example 2 has a construction 20 similar to that of Figure 3.

Referring to Figure 3, Example 2 forms a VCSEL stacked structure on an n-GaAs monocrystal (100) substrate 61 by consecutively stacking, by way of an MOCVD process, a first lower semiconductor DBR 25 62 in which an n-AlAs/ $\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$ pair is repeated for

47.5 times, a second lower semiconductor DBR 63 in which an $n\text{-Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$ pair is repeated ten times, a $(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$ lower spacer layer 64A, an $\text{In}_{0.46}\text{Ga}_{0.54}\text{P}/(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$ (well/barrier) TQW active layer 64B, a $(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$ upper spacer layer 64C, a p-AlAs selective oxidation layer 65, an upper semiconductor DBR 66 in which a p- $\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$ pair is repeated 40.5 times, and a p-GaAs contact layer 67.

10 Next, a circular mesa mask is patterned on such a VCSEL stacked structure thus formed by a photoresist, and mesa etching is conducted by an ICP etching method by introducing a Cl_2 gas.

 In the present embodiment, time-change of
15 the emission intensity of In (451nm) is monitored by a plasma emission spectrometer during this plasma etching process. With progress of the etching, emission of In (451nm) is detected, while this emission disappears in the meantime. Thus, by
20 terminating the etching process at the moment the emission of In has disappeared, a mesa structure M, in which the mesa etching has stopped in the second lower semiconductor DBR 63, is obtained.

 Next, at the moment the mesa structure M is
25 formed, the AlAs selective oxidation layer 65 is

annealed in water vapor ambient at 400°C, and there is formed a current confinement structure inside the AlAs layer for selective oxidation 65 such that the non-oxidized AlAs region has an area of $25\mu\text{m}^2$.

5 Further, the surrounding area of the mesa structure is filled with a polyimide protective film 68 excluding the part used for electrode contact and the part used for optical exit.

Next, a p-side electrode film 69 is
10 deposited on the top surface of the mesa structure M in contact with the p-type contact layer 67 by an evaporation deposition process, and an opening for optical output is formed by a liftoff process. Further, an n-side electrode 70 is provided on the
15 rear side of the substrate 61 and the surface-emission laser diode of the construction shown in Figure 3 is fabricated.

With the surface-emission laser diode 80 of Example 2, positive carriers and negative carriers
20 are injected respectively from the p-side electrode 69 and the n-side electrode 70, and the laser beam of the wavelength of 650nm is emitted in the direction perpendicular to the substrate 61 via the opening formed in the upper electrode 69.

25 With the surface-emission laser diode 80 of

Example 2, it becomes possible to obtain surface-emission laser diodes of uniform laser characteristics similar to the surface-emission laser diode of Example 1 with high yield.

5

Example 3

Next, a surface-emission laser diode 100 according to Example 3 of the present invention will be explained. As noted before, the surface-emission laser diode 100 of Example 3 has a construction similar to that of Figure 3.

Referring to Figure 3, Example 3 forms a VCSEL stacked structure on an n-GaAs monocrystal (100) substrate 61 by consecutively stacking, by way of an MOCVD process, a first lower semiconductor DBR 62 in which an n-AlAs/ $\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$ pair is repeated for 40.5 times, a second lower semiconductor DBR 63 in which an $\text{n-Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$ pair is repeated five times, an $\text{In}_{0.27}\text{Ga}_{0.73}\text{As}_{0.44}\text{P}_{0.56}$ lower spacer layer 64A, an GaAs/ $\text{In}_{0.27}\text{Ga}_{0.73}\text{As}_{0.44}\text{P}_{0.56}$ (well/barrier) TQW active layer 64B, an $\text{In}_{0.27}\text{Ga}_{0.73}\text{As}_{0.44}\text{P}_{0.56}$ upper spacer layer 64C, a p-AlAs selective oxidation layer 65, an upper semiconductor DBR 66 in which a p- $\text{Al}_{0.95}\text{Ga}_{0.05}\text{As}/\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$ pair is repeated 30.5 times, and a p-GaAs contact layer 67.

Next, mesa etching is conducted to the VCSEL stacked structure similarly to Example 2, and after similar thermal annealing process, the surrounding area of the mesa structure M is filled
5 with a polyimide film 68, followed by electrode formation. With this, the surface-emission laser diode 100 of Figure 3 is obtained.

With the surface-emission laser diode 100 of Example 3, positive carriers and negative carriers
10 are injected respectively from the p-side electrode 69 and the n-side electrode 70, and the laser beam of the wavelength of 850nm is emitted in the direction perpendicular to the substrate 61 via the opening formed in the upper electrode 69.

15 With the surface-emission laser diode of Example 3, too, it becomes possible to obtain surface-emission laser diodes of good heat dissipation characteristics and uniform laser characteristics similar to the surface-emission laser
20 diode of Example 1 with high yield.

Example 4

Next, a surface-emission laser diode 120 according to Example 4 of the present invention will be explained. As noted before, the surface-emission
25 laser diode 120 of Example 4 has a construction

similar to that of Figure 3.

Referring to Figure 3, Example 4 forms a VCSEL stacked structure on an n-GaAs monocrystal (100) substrate 61 by consecutively stacking, by way of an MOCVD process, a first lower semiconductor DBR 62 in which an n-AlAs/GaAs pair is repeated for 32.5 times, a second lower semiconductor DBR 63 in which an n-Al_{0.95}Ga_{0.05}As/n-GaAs pair is repeated three times, a Ga_{0.5}In_{0.5}P lower spacer layer 64A, a GaInNAs/GaAs (well/barrier) TQW active layer 64B, a Ga_{0.5}In_{0.5}P upper spacer layer 64C, a p-AlAs selective oxidation layer 65, an upper semiconductor DBR 66 in which a p-Al_{0.95}Ga_{0.05}As/p-GaAs pair is repeated 26 times, and a p-GaAs contact layer 67.

Next, mesa etching is conducted to the VCSEL stacked structure similarly to Example 2, and after similar thermal annealing process, the surrounding area of the mesa structure M is filled with a polyimide film 68, followed by electrode formation. With this, the surface-emission laser diode 120 of Figure 3 is obtained.

With the surface-emission laser diode 120 of Example 4, positive carriers and negative carriers are injected respectively from the p-side electrode 69 and the n-side electrode 70, and the laser beam of

the wavelength of 1300nm is emitted in the direction perpendicular to the substrate 61 via the opening formed in the upper electrode 69.

With Example 4, the active layer contains
5 GaInNAs, and thus, in addition to the function and effect of Example 1 explained before,
it becomes possible to construct a laser device of the 1.3 μ m band also on the GaAs substrate. Thereby,
it becomes possible to use the high performance DBR
10 of the AlGaAs system and it becomes further possible to use the selectively oxidized confinement structure. Further, because of large band discontinuity between the barrier layer or spacer layer and the GaInNAs active layer, the efficiency of
15 carrier confinement is improved further and the characteristic temperature is improved further. Thereby, a surface-emission laser diode applicable widely for the optical source of optical transmission is obtained.

20 Further, because the surface-emission laser diode of the present embodiment is the device of the 1.3 μ m band, it is possible to conduct the mesa etching such that the bottom of the etching is located inside the second lower DBR 63, even in the
25 case the semiconductor layers constituting the DBRs

62 and 63 have a large thickness and the second lower DBR 63 has the thickness of only three pairs. With this, heat dissipation characteristics and temperature characteristics are improved further, and
5 it becomes possible to drive the surface-emission laser diode with further higher power.

Example 5

Figure 5 shows the construction of a surface-emission laser diode 140 according to Example
10 5.

Referring to Figure 5, Example 5 forms a VCSEL stacked structure on an p-GaAs monocrystal (100) substrate 61 by consecutively stacking, by way of an MOCVD process, a first lower semiconductor DBR
15 82 in which a p-AlAs/p-Al_{0.15}Ga_{0.85}As pair is repeatedly stacked for 39.5 times, a second lower semiconductor DBR 83 in which a p-Al_{0.95}Ga_{0.05}As/p-Al_{0.15}Ga_{0.85}As pair is repeatedly stacked for six times, a p-AlAs layer for selective oxidation 84, an
20 In_{0.27}Ga_{0.73}As_{0.44}P_{0.56} lower spacer layer 85A, a GaAs/In_{0.27}Ga_{0.73}P_{0.56} (well/barrier) TQW active layer 85B, an In_{0.27}Ga_{0.73}As_{0.44}P_{0.56} upper spacer layer 84C, an upper semiconductor DBR 86 in which an n-Al_{0.95}Ga_{0.05}As/n-Al_{0.15}Ga_{0.85}As pair is repeatedly
25 stacked for 30.5 times, and an n-GaAs contact layer

87. Here, the lower spacer layer 85A, the active layer 85B and the upper spacer layer 84c forms an active structural part 85 serves for the cavity.

Next, mesa etching is conducted to the
5 VCSEL stacked structure similarly to Example 2, and after similar thermal annealing process, the surrounding area of the mesa structure M is filled with a polyimide film 80, followed by electrode formation. With this, the surface-emission laser
10 diode 120 of Figure 3 is obtained. With the present invention, it should be noted that the p-side electrode 89 is provided on the rear surface of the substrate 81 and the n-side electrode 88 is formed on the contact layer 87.

15 With the surface-emission laser diode 120 of Example 5, negative carriers and positive carriers are injected respectively from the n-side electrode 88 and the p-side electrode 89, and the laser beam of the wavelength of 850nm is emitted in the direction
20 perpendicular to the substrate 81 via the opening formed in the upper electrode 88.

In the surface-emission laser diode such as the one shown in Figure 5, there is a need of providing the AlAs layer for selective oxidation 84
25 at the side closer to the substrate as compared with

the active structural part 85 in the event the semiconductor layers at the substrate side of the active layer 85B in the active structural part 85 are formed to have the p-conductivity type. This is because, with compound semiconductors, mobility is smaller in the p-conductivity type layer as compared in the n-conductivity type layer and larger confinement effect is obtained by providing the current confinement structure in the p-type conductive region.

As noted above, when forming the semiconductor layers at the side of the substrate in the p-conductivity type, there is a need of more precise etching control. With the stacked film construction of Example 5, it is possible to carry out stable mesa etching by monitoring the progress of the etching by using the plasma atomic emission spectrometry, even in the case the surface-emission laser diode use semiconductor layers of p-conductivity type at the side closer to the substrate.

Other features of the present invention are similar to those of Example 1 explained before, and description thereof will be omitted.

Example 6

Next, a surface-emission laser diode according to Example 6 of the present invention will be explained.

Figures 6 through 7 show the construction of a surface-emission laser diode 160 according to Example 6 of the present invention, wherein Figure 7 is an enlarged view showing a region A in the vicinity of the active layer of the surface-emission laser diode 160 of Figure 6. It should be noted that the surface-emission laser diode of Example 6 oscillates at the wavelength of 780nm.

Referring to Figure 6, the surface-emission laser diode 160 includes, on an n-(100)GaAs substrate 101 having a surface orientation inclined in a direction of (111)A surface with an inclination angle 15° , a first lower semiconductor DBR (lower first reflector) 102 formed of a periodic structure in which an n-AlAs low refractive index layer and an n- $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ high refractive index layer are stacked alternately for 30.5 periods with the thickness corresponding to $1/4$ times the oscillation wavelength in the medium; and a second lower semiconductor DBR (lower second reflector) 103 formed of a periodic structure in which an n- $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ low refractive index layer and an n- $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ high refractive index

layer are stacked alternately with the thickness corresponding to $1/4$ times the oscillation wavelength in the medium. It should be noted that Figure 6 omits detailed illustration.

5 In the first lower semiconductor DBR 102 and the second lower semiconductor DBR 103, there is imposed a compositional graded layer of the thickness of 20nm and having the Al content changed gradually from one value to the other value between every layer
10 that constitutes the DBR, and the thickness including the graded layer is set to be equal to $1/4$ times the oscillation wavelength in the medium. With such a construction, the band discontinuity between the high refractive index layer and the low refractive index
15 layer is relaxed at the time of causing to flow current to the DBR, and the resistance of DBR can be reduced.

 Further, on the second layer semiconductor DBR 103, there are stacked consecutively, an
20 $(\text{Al}_{0.7}\text{Ga})_{0.5}\text{In}_{0.5}\text{P}$ lower first spacer (cladding) layer 104A that achieves lattice matching to the second layer semiconductor DBR 103; a $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ lower second spacer layer 104B that achieves lattice matching to the $(\text{Al}_{0.7}\text{Ga})_{0.5}\text{In}_{0.5}\text{P}$ lower first spacer (cladding)
25 layer; a quantum well active layer 104C in which

three GaInPAs quantum well layers 104a having a compressive strain composition and a bandgap wavelength of 780nm and two $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ barrier layers 104b of a lattice-matching composition to the
5 substrate are stacked alternately; a $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ upper second spacer layer 104D; and an $(\text{Al}_{0.7}\text{Ga})_{0.5}\text{In}_{0.5}\text{P}$ upper first spacer (cladding layer) 104E.

The semiconductor layers 104A - 104E form a cavity 104 of one wavelength, and there is formed, on
10 the cavity 104, an upper semiconductor DBR (upper reflector) 105 of a periodic structure in which a p- $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.9$) low refractive index layer and a p- $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.3$) high refractive index layer are stacked alternately for 25 periods, for example
15 (details are omitted in Figure 6). With the present example, it should be noted that a compositional graded layer is interposed between the low refractive index layer and the high refractive index layer also in the upper reflector 105, similarly to the lower
20 reflector 102 and 103.

Further, a p-GaAs contact layer 106 is formed on the upper reflector 105. As explained before, there is formed a cavity of one oscillation wavelength (so-called lambda cavity) between the
25 lower reflector 103 and the upper reflector 105 with

the present embodiment.

Hereinafter, the fabrication process of the surface-emission laser diode 160 of Example 6 will be explained.

5 With the present embodiment, the growth of the semiconductor layers 102 - 106 is conducted by an MOCVD process, wherein TMG (trimethyl gallium), TMA (trimethyl aluminum), TMI (trimethyl indium), PH_3 (phosphine), and AsH_3 (arsine) are used for the
10 source according to the needs. Further, H_2Se (hydrogen selenide) is used for the n-type dopant and CBr_4 is used for the p-type dopant. Further, H_2 is used for the carrier gas.

 Because it is possible to form the
15 construction such as a compositional graded layer by controlling the supply amount of the source gases, MOCVD process is particularly suitable for the crystal growth method of a surface-emission laser diode that includes DBR. Further, it does not require
20 high vacuum state as in the case of MBE process and it is sufficient to merely control the supply flow rate of the source gases and the supply time, MOCVD process is suited for mass production. With Example 6, it should be noted that a part of the low
25 refractive index layer of the p-side DBR (upper

reflector) 105 close to the active layer 104C is formed by an AlAs layer 107.

After formation of such a VCSEL stacked structure, a mesa etching is conducted to a
5 predetermined depth, such that at least a sidewall surface of the p-AlAs layer 107 is exposed, and with this, a mesa structure M is formed. Further, the AlAs layer 107 exposed by the mesa structure M is oxidized in water vapor ambient, starting from the exposed
10 sidewall surface, and there is formed an Al_xO_y current confinement part 107A in the AlAs layer 107.

Further, the space surrounding the mesa structure M formed by the mesa etching is filled with the polyimide film 108 for planarization, and
15 thereafter, the polyimide film 108 is removed from the p-contact layer 106 and the upper reflector in correspondence to a predetermined optical exit part 109A, and a p-side electrode 109 is formed on the p-contact layer 106 so as to avoid the optical exit
20 part 109A. Further, an n-side electrode 110 is formed on the rear side of the substrate 101.

With Example 6, current confinement is achieved by selective oxidation of the layer for selective oxidation 107 that contains Al and As as
25 the major components, and with this, threshold

current is reduced. With the current confinement structure that uses an Al oxide film 107A formed by selective oxidation of the layer for selective oxidation 107, it becomes possible to form the
5 current confinement layer 107A near the active layer 104C, and diffusion of the injected holes is suppressed, and it becomes possible to efficiently confine the carriers into a minute region not exposed to the air. Further, with such a current confinement
10 structure, there occurs a decrease of refractive index when the AlAs film 107 is oxidized to form the Al oxide film 107A, and it becomes possible to confine the light to the minute region where the carriers are confined by way of convex lens effect.
15 Thereby, efficiency of stimulated emission is improved significantly, and with this, the threshold current is decreased. Further, such a construction can easily form a current confinement structure, and it becomes possible to reduce the production cost of
20 the surface-emission laser diode.

Further, with the surface-emission laser diode 160 of Example 6, which uses AlGaInP for a part of the spacer layers 104A and 104E and GaInPAs for the barrier layer and the quantum well active layer,
25 and forms the semiconductor layers on the (100) GaAs

substrate of the surface orientation inclined in the (111)A direction by 15° , it becomes possible to suppress the narrowing of bandgap associated with formation of natural superlattices, deterioration of surface morphology caused by hillock (hill-like defect) formation, or the effect of non-optical recombination centers.

Further, with the surface emission laser diode 160, it should be noted that $(\text{Al}_{0.7}\text{Ga})_{0.5}\text{In}_{0.5}\text{P}$, which is a widegap material, is used for the spacer layer (cladding layer) 104A and 104E. Because of this, the bandgap difference between the spacer layers 104A and 104E and the quantum well active layer 104a increases to 743mV from 466meV (Al content 0.6) for the case the spacer layer is formed of AlGaAs. Further, the surface-emission laser diode 160 is advantageous with regard to the bandgap difference between the barrier layer 104b and the quantum well active layer 104a, and excellent carrier confinement is realized.

Further, because the quantum well active layer 104a accumulates therein a compressive strain, it is also attained the increase of gain caused by band splitting of heavy holes and light holes. With these, the surface-emission laser diode 160 has a

very high gain and it is possible to perform high output power operation at low threshold.

Further, because the quantum well active layer 104a and the barrier layer 104b are formed of the material free from Al, incorporation of oxygen into these layers is reduced, and it becomes possible to suppress formation of non-optical recombination centers. With this, it becomes possible to realize a surface-emission laser diode of long lifetime.

10 Further, with the surface-emission laser diode 160 of the present example, control of polarization direction is achieved by utilizing the optical gain anisotropy caused by inclination of the substrate.

15 When compared with the surface-emission laser diode that uses the (311)B substrate (inclination angle 25°), which is thought most promising at the present juncture, the surface-emission laser diode of the present embodiment uses a
20 small inclination angle (15°), and thus, the optical gain anisotropy becomes inevitably small. Thus, with the surface-emission laser diode 160 of Example 6, this decrease of the optical gain anisotropy is compensated for by the increase of the optical gain
25 anisotropy caused by providing a compressive strain

to the quantum well active layer. With such a construction, it becomes possible to realize a satisfactory polarization control.

Thus, according to Example 6 of the present invention, the gain of the active layer 104a is increased and heat dissipation is improved, and with this, it becomes possible to realize a high output power surface-emission laser diode of 780nm wavelength band having low threshold value for laser oscillation, good reliability and controlled polarization direction.

It should be noted that the foregoing effect of the present invention decreases at short wavelength band, but it appears conspicuously in the wavelength band longer than 680nm. For example, when compared with the surface-emission laser diode of the 780nm band that uses the active layer of AlGaAs/AlGaAs system, it should be noted that the bandgap difference between the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.6$, $E_g=2.0226\text{eV}$) having the largest bandgap in the typical compositional range used for $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) system spacer layer and the active layer of the compositional wavelength 780nm ($E_g=1.5567\text{eV}$), is generally equal to the bandgap difference (460meV) between the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($a=0.7$, $b=0.5$,

$E_g=2.289\text{eV}$) having the largest bandgap in the typical compositional range used for the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1, 0 \leq b \leq 1$) spacer layer and the active layer of the compositional wavelength of 680nm ($E_g=1.8233\text{eV}$).

5 Further, with regard to the bandgap difference between the barrier layer and the quantum well active layer, the bandgap different to the active layer of the compositional wavelength of 680nm becomes about 200meV when the barrier layer is formed
10 of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($e=0.6, f=1, E_g=2.02\text{eV}$), while this is generally equivalent to the case of the surface-emission laser diode of 780nm that uses the $\text{AlGaAs}/\text{AlGaAs}$ system active layer.

 This means that it becomes possible to
15 achieve the carrier confinement equivalent to or superior to the case of the surface-emission laser diode of the 780nm band that uses the active layer of the $\text{AlGaAs}/\text{AlGaAs}$ system while using an Al-free active layer (quantum well active layer and barrier
20 layer) by using the spacer layer of the AlGaInP system, provided that the compositional wavelength is longer than 680nm . Further, by taking into consideration the effect of the strained quantum well active layer, it becomes possible with the surface-
25 emission laser diode of the present example to have

the characteristics equal to or superior to the surface-emission laser diode of the 780nm band that uses the conventional active layer of the AlGaAs/AlGaAs system.

5 Example 7

Next, a surface-emission laser diode according to Example 7 of the present invention will be explained.

Figure 8 is a top view diagram of the
10 surface-emission laser diode 180 of Example 7. The surface-emission laser diode 180 of Example 7 has a cross-sectional structure identical to that of the surface-emission laser diode 160 of Example 6, except that the mesa structure M thereof is formed with
15 anisotropy such that the mesa structure M forms an elongated circular shape in the (111)A direction when viewed from the light emission direction of the surface-emission laser diode. Thus, explanation about the cross-sectional structure of the surface-emission
20 laser diode 180 is omitted. Further, because the mesa structure has the elongated elliptic shape, the current injection region 107 defined by the Al oxide film 107A also has an elongated shape in the direction of the (111)A surface. It should be noted
25 that the foregoing shape anisotropy is not limited to

elongated elliptic shape but it is possible to use other shape such as rectangular shape.

The present embodiment uses optical gain anisotropy caused by the inclination of the substrate
5 101 for the polarization control. However, the inclination angle is small (15°) as compared with the case of using the (311)B substrate (inclination angle 25° , which is thought most promising at the current juncture, for the polarization control, and thus, the
10 obtained optical gain anisotropy becomes inevitably small.

With Example 7, such decrease of the optical gain anisotropy is compensated for by increasing the optical gain in the inclination
15 direction of the substrate (direction of (111)A surface), by increasing the optical gain anisotropy by providing a compressive strain to the quantum well active layer 104a and further by providing anisotropy to the outer shape of the active layer as viewed from
20 the optical emission direction of the surface-emission laser diode 180, more specifically, by using an elongated shape in the direction of the (111)A surface. Thereby, polarization control comparable to the case of using the (311)B substrate is realized.

25 Example 8

Next, a surface-emission laser diode of Example 7 of the present invention will be explained.

Figure 9 shows the construction of surface-emission laser diode 200 of Example 7.

5 The surface-emission laser diode 200 of Figure 9 has a construction similar to that of the surface-emission laser diode of Example 6, wherein it should be noted that Figure 9 shows the region around the active layer of the surface-emission laser diode
10 of Example 8 in enlarged scale.

Referring to Figure 9, the surface-emission laser diode 200 of Example 8 is different from the surface-emission laser diode 160 of Example 6 in the point that $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ having a tensile strain is used
15 for the barrier layer 104b. Further, with Example 8, the barrier layer of $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ having the tensile strain is provided also under the first quantum well active layer 104a and over the third quantum well active layer 104a. Other structure is identical to
20 the surface-emission laser diode 160 of Figure 6.

When comparison is made for the GaInPAs system having the same lattice constant, GaInP has the largest bandgap. Further, in the case of using GaInPAs for the barrier layer 14b, it becomes
25 possible to secure a large bandgap when the

composition of small lattice constant is used. Thereby, the band discontinuity to the quantum well active layer 104a can be increased further, and it becomes possible to obtain further low-threshold
5 operation and high output power operation. For example, the tensile-strained $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ layer used with Example 8 has a bandgap of 2.02eV, while this bandgap is larger than that of a $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ lattice matched layer of Example 6, which has the bandgap of
10 1.87eV, by 150meV.

Example 9

Figure 10 is a top view diagram of a surface-emission laser diode array 220 according to Example 9 of the present invention.

15 Referring to Figure 10, there are provided ten surface-emission laser diodes 200 of Example 8 on the substrate 101 with the surface-emission laser diode array 220 in one-dimensional array, except that, in Example 9, p-side and n-side of the surface-
20 emission laser diode 220 are exchanged. Thus, with Example 9, the GaAs substrate 101, on which the surface-emission laser diode 220 is formed, is a substrate, and there are provided n-side electrode pads 109 on the top surface and a p-side common
25 electrode 110 is provided on the rear side.

While plural surface-emission laser diodes 200 are arranged with the example of Figure 10 in one-dimensional array, it is possible to arrange such surface-emission laser diodes in two dimensional
5 array.

Example 100

Figure 11 shows an optical transmission module 240 of Example 10.

Referring to Figure 11, the optical
10 transmission module 240 has a construction of combining low-cost acrylic POFs (plastic optical fibers) 240 with the surface-emission laser diode array chip of Figure 10. Thus the laser beam 241A from each surface emission laser diode 200 is
15 injected into a corresponding POF 241 and transmitted therethrough.

An acrylic POF shows the minimum absorption loss at the wavelength of of 650nm, and thus, the use of surface-emission laser diode of 650nm has been
20 studied. However, conventional surface-emission laser diode of 650nm band has poor high temperature characteristics, and practical use thereof has not been successful. In view of these circumstances, LEDs have been used with the optical transmission modules
25 that use such POF. However, it is difficult to

conduct high-speed modulation with LED, and it is thought indispensable to use a laser diode for achieving high-speed transmission exceeding 1Gbps.

With the surface-emission laser diode 200
5 used with the optical transmission module of Example 10, the laser oscillation wavelength is 780nm. However, the surface-emission laser diode has excellent heat dissipation characteristics and large active layer gain, and it is possible to perform high
10 output power operation. Further, because it has excellent high temperature characteristics, it is possible to conduct optical transmission for short distance, in spite of the fact that there is a problem of absorption loss by POF.

15 In the field of optical communication, parallel transmission is attempted for transmitting larger amount of data at the same time by using a laser array in which plural laser diodes are integrated. With this, high-speed parallel
20 transmission becomes possible and it becomes possible to transmit larger amount of data at the same time.

With Example 10 shown in Figure 11, the surface-laser diode elements 100 in the surface-laser diode array and the optical fibers 241 are provided
25 in one to one correspondence, while it is also

possible to increase the transmission speed further by conducting wavelength multiplexed transmission via a single optical fiber by arranging plural surface-emission laser diode elements of different
5 wavelengths in the form of one-dimensional or two-dimensional array.

Further, the present example combines the low-cost surface-emission laser diode element 200 with low-cost POF 241, and thus, it becomes possible
10 to realize a low-cost optical transmission module, and with this, it becomes possible to realize a low-cost optical communication system. Because such optical communication system is extremely low cost, it is useful for short-distance data communication in
15 homes, in office rooms and inside of apparatuses.

Example 11

Figure 12 shows the construction of an optical transceiver module 260 according to Example
11 of the present invention.

20 Referring to Figure 12, the optical transceiver module 260 has a construction that combines the surface-emission laser diode element 200 of Example 8, a photodiode 261 for reception and an acrylic POF 262.

25 Both of the surface-emission laser diode

200 of the present invention and POF 262 are low cost, and it becomes possible, with the optical transceiver system 260 that uses the surface-emission laser diode element 200 of the present invention for
5 the optical communication system, to realize a low-cost optical communication system by constructing the optical transceiver module by combining the surface-emission laser diode element 200 for transmission and the photodiode 261 for reception, with a single POF
10 262.

Further, in view of the fact that POF has a large fiber diameter and it is possible to reduce the mounting cost because of the easiness of coupling to a fiber, it becomes possible to reduce the cost of
15 the optical transceiver module 260 further. Further, in view of the fact that the surface-emission laser diode 200 of the present invention has excellent temperature characteristics and low laser oscillation threshold, the amount of heat generation is small and
20 it becomes possible to realize a low-cost optical communication system that can be used up to high temperatures without cooling.

The optical communicating system 260 according to the present embodiment is particularly
25 useful for short-distance communication such as the

optical transmission between devices such as computers by way of LAN (Local Area Network) that uses POF, the optical communications between LSIs on a board, the optical interconnection between elements
5 inside an LSI, and the like.

Meanwhile, the processing performance of LSIs is increasing recently, and it is predicted that the transmission speed of the part connecting such LSIs becomes the bottleneck problem.

10 On the other hand, by changing the signal connection inside the system from electrical connection to optical interconnect, and by using the optical transmission module 240 or the optical transceiver module 260 for connecting the boards of a
15 computer system, the LSIs in a board or elements inside an LSI, it becomes possible to realize a super-fast computer system.

Further, by using the optical transmission module 220 or the optical transceiver module 260 of
20 the present invention for connection plural computer systems, it becomes possible to construct a super-fast network system. Particularly, the power consumption can be reduced significantly with the surface-emission laser diode as compared with the
25 edge-emission laser diode, and because of easiness of

forming a two-dimensional array with the use of surface-emission laser diode elements, the present invention is particularly suited for constructing an optical communication system of parallel transmission type.

Example 12

Figure 13 shows the construction of a laser printer 280 according to Example 12, wherein it should be noted that the laser printer 280 of Figure 13 combines a surface-emission laser diode array chip (16 beam VSCEL array) 281, in which the surface-emission laser diodes 200 of Example 8 having the oscillation wavelength of 780nm are arranged on the GaAs substrate 101 in the form of a 4×4 two-dimensional array, with a photosensitive drum 282. Figure 13 particularly shows the outline of optical scanning part of the laser printer 280.

Figure 14 is a top view showing the outline construction of the surface-emission laser diode array chip (16 beam VCSEL array) 281 used with the laser printer 280 of Figure 13. With such a surface-emission laser diode array chip (16 beam VCSEL array) 281, it is possible to realize the situation equivalent to the case the optical sources are aligned on the photosensitive body 282 in the sub-

scanning direction V-SCAN with an interval of $10\mu\text{m}$ as shown in Figure 14, by adjusting the timing of turning-on.

With Example 12, the plural optical beams
5 from the plural surface-emission laser diode array
200 are focused upon a scanning polygonal mirror 284
via an optical system including a lens 283 and form
plural optical spots aligned in the sub-scanning
direction V-SCAN by adjusting the timing of turning-
10 on while rotating the polygonal mirror 284 at high
speed. The plural optical beams are then focused upon
the photosensitive body 282 serving for the scanning
surface via a so-called f- θ lens for image formation.
Thus, according to the present embodiment, the image
15 formation is made by scanning plural beams at the
same time.

According to Example 12, it becomes
possible to carry out optical writing on the
photosensitive body 282 with an interval of about
20 $10\mu\text{m}$ in the sub-scanning direction V-SCAN, while this
corresponds to the resolution of 2400DPI (dot/inch).
On the other hand, the writing interval in the main
scanning direction HSCAN can be controlled easily by
the turn-on timing of the optical source.

25 With the laser printer 280 of the present

embodiment, it becomes possible to write 16 dots at the same time, and it becomes possible to perform high-speed printing. Further, by increasing the number of the surface-emission laser diodes 200 in
5 the array, a further high speed printing becomes possible. Further, by adjusting the interval between the surface-emission laser diode elements 200, the dot interval in the sub-scanning direction H-SCAN can be adjusted, and it becomes possible to carry out
10 high-quality printing with the density higher than 2400DPI. With the surface-emission laser diode of Example 12, the efficiency is improved over the conventional surface-emission laser diode. Further, it has superior heat dissipation characteristics and
15 it becomes possible to maintain high output power even when plural elements are operated at the same time. Thereby, it becomes possible to increase the printing speed.

While Example 12 has shown the application
20 of the laser to laser printer, the surface-emission laser diode of the present invention is applicable to other image forming apparatuses. Further, the surface-emission laser diode of the present invention is applicable also to the optical source for
25 recording and playback in CDs, or the like. Thus, the

present invention is applicable to an optical pickup system. Further, the present invention is applicable to optoelectronic hybrid integrated circuit, or the like.

5 In Examples 9 - 12, it is also possible to use a surface-emission laser diode of any modes explained before or to be explained below in place of the surface-emission laser diode 200.

(TWELFTH MODE)

10 Hereinafter, twelfth mode of the present invention will be explained with reference to Figures 15 and 16, wherein it should be noted the twelfth mode of the present invention relates to the principle of the construction and operation of the
15 surface-emission laser diode.

(1) First Construction

 The surface-emission laser diode according to the first construction of the twelfth mode of the present invention comprises a GaAs substrate; a
20 cavity region formed over said GaAs substrate, said cavity region including at least one quantum well active layer producing a laser light and barrier layers; and an upper reflector and a lower reflector provided at a top part and a bottom part of said
25 cavity region over said GaAs substrate, said upper

reflector and/or said lower reflector including a semiconductor Bragg reflector, at least a part of said semiconductor distributed Bragg reflector comprising a semiconductor layer containing Al, Ga and As as major components, wherein there is provided, between said active layer and said semiconductor layer that contains Al, Ga and As as major components, a semiconductor layer containing Al, In and P as major components such that said semiconductor layer containing Al, In and P as major components is provided adjacent to said semiconductor layer that contains Al, Ga and As as major components, an interface between said semiconductor layer containing Al, Ga and As as major components and said semiconductor layer containing Al, In and P as major components being formed coincident to a location of a node of electric field strength distribution.

With the surface-emission laser diode of the first construction, the semiconductor layer containing Al, In and P as the major components is formed, for example by $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$).

In conventional surface-emission laser diodes, the interface between the cavity region and

the reflector is located coincident to the anti-node of the electric field strength distribution and the semiconductor layer containing Al, In and P as the major components is provided at the uppermost part of the cavity region. Thus, the interface between to the upper reflector formed of the semiconductor layer containing Al, Ga and As as the major components is formed at the location where the effect of optical absorption appears most conspicuously. Meanwhile, when conducting crystal growth of a semiconductor layer containing Al, Ga and As as the major components on the semiconductor layer containing Al, In and P as the major components, there is a tendency that segregation of In such as In carry over takes place, and thus, there has been a need of suppressing this problem. Conventionally, it has been difficult to avoid increase of the threshold value. It should be noted that this problem appears conspicuous when conducting crystal growth of a semiconductor layer containing Al, Ga and As as the major components, on the semiconductor layer containing Al, In and P as the major components.

Contrary to the foregoing, with the surface-emission laser diode of the first construction, in which the interface 3 between the

semiconductor layer 1 containing Al, In and P as the major components and the semiconductor layer 2 (part of the upper reflector) containing Al, Ga and As as the major components, is located at the node N of the electric field strength distribution, the surface-emission laser diode is designed so as to drastically decrease the effect of the optical absorption at the interface 3, and it becomes possible to suppress the increase of laser oscillation threshold value effectively even when there has been caused some segregation of In. In Figure 1, it should be noted that the anti-node of the electric field strength distribution is represented by N.

Here, it is further advantageous to provide a thin layer for In segregation suppression between the semiconductor layer 1 containing Al, In and P as the major component and the semiconductor layer 2 (part of the upper reflector) containing Al, Ga and As as the major components, for the purpose of suppressing In segregation.

For the semiconductor layer 1 that contains Al, In and P as the major components, it is possible to use a $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq a$) layer. With such a construction, the effect of decrease of the threshold value is attained for the surface-emission

laser diode that uses AlGaInP layer, irrespective of the wavelength, and thus, not only in the red color surface-emission laser diode of the 650nm band, in which the use of AlGaInP layer is essential, but also
5 in the surface-emission laser diodes of the 780nm band, 850nm band, or the like.

(2) Second Construction

The surface-emission laser diode according to the second construction of the second mode of the
10 present invention comprises: a GaAs substrate; a cavity region formed over said GaAs substrate and having at least one quantum well active layer producing a laser light and barrier layers; and an upper reflector and a lower reflector provided at a
15 top part and a bottom part of said cavity region over said GaAs substrate, said upper reflector and/or lower reflector including a semiconductor distributed Bragg reflector, at least a part of said semiconductor distributed Bragg reflector comprising
20 a semiconductor layer containing Al, Ga and As as major components, there being provided, between said active layer and said semiconductor layer containing Al, Ga and As as major components, a $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer adjacent to said semiconductor
25 layer containing Al, Ga and As as major components,

said $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer being added with Mg (magnesium) as a p-type dopant, said semiconductor layer containing Al, Ga and As as major components being added with C (carbon) as a p-type
5 dopant.

For the p-type dopant of the semiconductor layer containing Al, In and P as the major components, Zn (zinc) is used commonly, while Zn has a large diffusion coefficient and tends to cause
10 diffusion to the active layer or near the active layer, and there arises the problem of degradation of the device characteristics, such as decrease of efficiency of photoemission caused by degradation of the crystal quality, or increase of the absorption
15 loss.

Contrary to this, Mg, which can be used for the p-type dopant, is characterized by smaller diffusion coefficient as compared with Zn and the foregoing problem can be improved. On the other hand,
20 in the semiconductor layer that contains Al, Ga and As as the major components, C has an even smaller diffusion coefficient. Further, addition of Mg to the material containing As causes the problem of poor controllability of doping caused by memory effect.

25 Thus, with the present construction, Mg is

added primarily to the semiconductor layer containing Al, In and P as the major components and C is added to the semiconductor layer containing Al, Ga and As for the major components. With this, diffusion of
5 dopant or memory effect is suppressed, and the controllability of doping is improved, and the doping profile close to the designed profile is obtained. Further, degradation of crystal quality of the active layer is suppressed and high output power operation
10 and low threshold value are realized.

(3) Third Construction

The surface-emission laser diode according to the third construction of the twelfth mode of the present invention comprises: a GaAs substrate; a
15 cavity region formed over said GaAs substrate, said cavity region including at least one quantum well active layer producing a laser light and barrier layers; and an upper reflector and a lower reflector provided at a top part and a bottom part of said
20 cavity region over said GaAs substrate, said upper reflector and/or lower reflector including a semiconductor distributed Bragg reflector, at least a part of said semiconductor distributed Bragg reflector comprising a semiconductor layer containing
25 Al, Ga and As as major components, there being

provided, between said active layer and said semiconductor layer containing Al, Ga and As as major components, a $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer adjacent to said semiconductor layer containing Al, Ga and As as major components, said $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer being a semiconductor layer formed of a short period superlattice structure of AlInP and GaInP.

Although it changes depending on the material, thermal resistance of a semiconductor layer increases with increasing number of the elements that constitutes the semiconductor material. Thus, AlGaInP, a quaternary material, has a large thermal resistance. Thus, the heat generated in such an active layer is not dissipated easily but is accumulated in the active layer and invites the temperature rise of the active layer. Thus, there has been a problem that the optical output saturates with small injection current.

In the case of surface-emission laser diode, it can be regarded, when there is formed a superlattice structure by stacking the layers having a thickness sufficiently smaller than the oscillating wavelength alternately, that it is optically equivalent to the case in which there is formed a

mixed crystal having an average composition by mixing these layers uniformly, although there is a report that there occurs slight increase of refractive index by forming the superlattice structure. Thus, it is
5 possible to construct a reflector by using the semiconductor layers thus constructed by the superlattice structure.

Here, in view of the fact that the thermal resistance of the ternary system material such as
10 AlInP or GaInP is smaller than that of AlGaInP, a quaternary material, and because of the fact that AlInP or GaInP can be lattice-matched to the GaAs substrate similarly to the case of AlGaInP, the present construction decreases the thermal resistance
15 by forming a superlattice structure in place of the conventional AlGaInP semiconductor layer of uniform composition, by choosing at least two materials of small thermal resistance as compared with the average composition. With this, the heat generated in the
20 active layer is efficiently dissipated, and temperature rise of the active layer by current injection is decreased. Further, it becomes possible to conduct the current injection with a higher level than conventional case, while this leads to higher
25 output, and it becomes possible to obtain a surface-

emission laser diode capable of operating at high output power.

(4) Fourth Construction

The surface-emission laser diode according to the fourth construction of the twelfth mode comprises: a GaAs substrate; a cavity region formed over said GaAs substrate, said cavity region including at least one quantum well active layer producing a laser light and barrier layers; and an upper reflector and a lower reflector provided at a top part and a bottom part of said cavity region over said GaAs substrate, said upper reflector and/or lower reflector including a semiconductor distributed Bragg reflector, at least a part of said semiconductor distributed Bragg reflector comprising a low refractive index layer of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) and a high refractive index layer of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$), one of said low refractive index layers constituting said upper reflector and/or said lower reflector and located closest to said active layer comprising $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$), an interface between said cavity region and said low refractive index layer of said upper reflector and/or said lower reflector located closest to said active layer being coincident to an anti-node of an electric strength

distribution.

Figure 16 shows the construction of the surface-emission laser diode according to the fourth construction.

5 Referring to Figure 16, the surface-emission laser diode of the fourth construction is constructed such that the interface 306 between the cavity region 304 including the active layer 307 and the upper reflector 305 is located coincident to the
10 anti-node AN of the electric field strength distribution in accordance with the conventionally used construction, while it should be noted that, with the construction of Figure 2, the interface 309 for the case of growing the semiconductor layer
15 (upper reflector 305) that contains Al, Ga and As as the major components on the foregoing $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) layer 308 is made coincident to the node N of the electric field strength distribution by forming the low refractive index layer ($\lambda/4$
20 thickness) 308 of the upper reflector 305 closest to the active layer 307 with $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$). With this, the effect of optical absorption at the interface 309 is decreased significantly, and it becomes possible to suppress the increase of the
25 threshold value effectively even in the case there is

caused some segregation of In. In Figure 16, the reference numeral 310 forms (a part of) the lower reflector. Further, in Figure 16, only a part of the upper reflector 305 is illustrated.

5 In the construction of Figure 16, it is possible to construct the lower reflector 310 by a first lower reflector that uses AlAs for the low refractive index layer, a second lower reflector that uses $\text{Al}_{x_1}\text{Ga}_{1-x_1}\text{As}$ ($0 < x_1 < 1$), and at least one $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) low refractive index layer,
10 consecutively from the side of the substrate.

 The thermal resistance of AlAs increases sharply when only a small amount of Ga is added. Contrary to this, the lower reflector 310 includes
15 AlAs having a small thermal resistance for the low refractive index layer, and thus, dissipation of the heat generated in the active layer 307 is improved and temperature rise at the time of driving is suppressed. Thereby, a high output power surface-
20 emission laser diode of excellent temperature characteristics is obtained. In the case of the structure that includes the current confinement structure that uses an Al oxide film, it becomes possible to stop the etching for mesa formation
25 between the layer for selective oxidation, which is

to be converted to the Al oxide film, and AlAs of the first lower reflector, by providing a second lower reflector of an AlGaAs low refractive index layer of small Al content between the first lower reflector
5 that uses the AlAs low refractive index layer and the layer containing In.

Further, in the case a high refractive index layer of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$) and a low refractive index layer of $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$,
10 $0 \leq b \leq 1$) are to be stacked in the upper reflector 305 or the lower reflector 310, it becomes possible to provide an $(\text{Al}_{a_1}\text{Ga}_{1-a_1})_{b_1}\text{In}_{1-b_1}\text{P}$ ($0 \leq a_1 < a \leq 1$, $0 \leq b_1 \leq 1$) intermediate layer (In segregation suppressor layer) at such an interface with Al content smaller than the
15 $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) low refractive index layer.

By inserting such intermediate layer of small Al content when stacking the $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$) high refractive index layer on the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) low refractive index layer,
20 the Al content at the interface is decreased, it becomes possible to form the $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$) high refractive index layer on the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) low refractive index layer easily over
25 a wide process condition.

Further, at the heterojunction between the material of AlGaAs system and the material of the AlGaInP system, there occurs an increase of band discontinuity in the valence band when the Al content
5 of the material of the AlGaInP system is large. Because the intermediate layer of small Al content is inserted, the band discontinuity of the valence band is decreased, and it becomes possible to decrease the electric resistance in the stacked direction.

10 Further, with the semiconductor distributed Bragg reflector that constitutes the p-type reflector in any of the upper reflector 305 or the lower reflector 310, it is possible to add C (carbon) to the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) low refractive index layer and
15 the $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($0 \leq y < x \leq 1$) high refractive index layer as a p-type dopant, and add Mg (magnesium) to the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) low refractive index layer 308 as a p-type dopant.

Further, it is possible that the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) low refractive index layer
20 308 may be the semiconductor layer formed of the short period super-lattice structure of AlInP and GaInP.

(5) Fifth Construction

25 The surface-emission laser diode according

to the fifth construction of the twelfth mode of the present invention is a surface-emission laser diode according to the fourth construction, wherein there is provided a spacer layer between the active layer
5 and the upper reflector and/or lower reflector, a part of the spacer layer comprises a $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 \leq a' \leq 1$, $0 \leq b' \leq 1$) layer, the quantum well active layer comprises a $\text{Ga}_c\text{In}_{1-c}\text{P}_d\text{As}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$) having a compressive strain, and the barrier layer is formed
10 of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$).

Thus, with the example of Figure 16, at least the low refractive index layer among the low refractive index layers constituting the upper reflector 305 and located closest to the active layer
15 307 is formed of an AlGaInP layer, and a material of the GaInPAs system is used for the barrier layer or the quantum well active layer.

Thus, it becomes possible to use the widegap material such as the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$,
20 $0 \leq b \leq 1$) low refractive index layer and the $(\text{Al}_a\text{Ga}_{1-a'})_b\text{In}_{1-b'}\text{P}$ ($0 \leq a' \leq 1$, $0 \leq b' \leq 1$) spacer layer for the cladding layer for carrier confinement, and the bandgap difference between the cladding layer and the quantum well active layer is increased further as
25 compared with the case in which the cladding layer

for carrier confinement is formed of the material of AlGaAs system. Here, it should be noted that the spacer layer is the layer provided between the active layer and the reflector in ordinary construction and performs the function of carrier confinement.

With regard to the carrier confinement, there are cases in which other low refractive index layers of the DBR close to the active layer perform the function in addition to the spacer layer. In the fifth construction, the $(Al_{a'}Ga_{1-a'})_{b'}In_{1-b'}P$ ($0 \leq a' \leq 1$, $0 \leq b' \leq 1$) spacer layer and the $(Al_aGa_{1-a})_bIn_{1-b}P$ ($0 < a \leq 1$, $0 \leq b \leq 1$) low refractive index layer can perform the function of the cladding layer.

Referring to Table 2 explained with the previous mode, for example, it becomes possible, with the 780nm surface-emission laser diode of the system of AlGaInP (spacer layer)/GaInPAs (quantum well active layer), to secure a bandgap difference between the spacer layer and the quantum well layer, and between the beerier layer and the quantum well layer, larger than the 850nm surface emission laser that uses the AlGaAs/AlGaAs system, by using an $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ layer of the bandgap E_g of 2.289eV for the spacer layer, a GaInPAs layer having the bandgap of 1.5567eV and accumulating a compressive

strain for the quantum well layer, and further by using $\text{Ga}_x\text{In}_{1-x}\text{P}$ having a bandgap E_g of accumulating a tensile strain for the barrier layer.

Further, referring to Table 2, there occurs
5 an increase of band splitting between the heavy holes and the light holes by forming the active layer 307 by the quantum well layer of compressive strain composition as explained with reference to the previous modes, and thus, there occurs an increase of
10 gain and decrease of the threshold value, and the laser oscillation efficiency is increased together with the laser output. It should be noted that this effect is not attained with the 850nm surface-emission laser diode of the AlGaAs/AlGaAs system.

15 Thus, with the fifth construction of the twelfth mode of the present invention, a high-efficiency and high output power surface-emission laser diode is obtained with the threshold value lower than that of the 850nm surface-emission laser
20 diode of the AlGaAs/AlGaAs system. Further, with the present construction, there occurs an increase of carrier confinement efficiency, and the threshold value is decreased also by the increase of gain attained by the use of the strained quantum well
25 active layer. With this, it becomes possible to

reduce the reflectivity of the DBR 305 at the optical exit side. Thereby, the output of the surface emission laser can be increased further.

Further, by constructing the quantum well layer in the quantum well active layer 307 by the $\text{Ga}_c\text{In}_{1-c}\text{P}_d\text{As}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$) layer, and by constructing the barrier layer in the quantum well active layer 307 by $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$), it becomes possible to form the active layer 307 by the material free from Al. With this, incorporation of oxygen into the active layer 307 is reduced similarly to the second mode explained before, and formation of the non-optical recombination centers is suppressed, and a long lifetime surface-emission laser diode is realized.

Thus, according to Fifth Construction of the present mode, it becomes possible to realize a reliable high output surface-emission laser diode operating at the wavelength shorter than 850nm, having large gain for the active layer and reduced threshold value, by using the AlGaInP material for a part of the spacer layer and by using GaInPAs for the barrier layer and the quantum well active layer.

While the fifth construction limits the wavelength to be shorter than 850nm, this is merely

because advantage over the conventional construction appears extremely conspicuously in this wavelength range, and the foregoing advantageous effect is attained more or less in the wavelength longer than
5 850nm.

Further, with the fifth construction, too, the bandgap of GaInP is the largest among the materials of the GaInPAs system used for the barrier layer in the quantum well active layer of the
10 surface-emission laser diode when comparison is made on the basis of the same lattice constant. Further, larger bandgap is secured with the material of the smaller lattice constant. Thus, by using the material of the GaInP system of small lattice constant for the
15 barrier layer, it becomes possible for the surface-emission laser diode to perform high output power operation with low threshold value. For example, it should be noted that the bandgap of a $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ tensile-strained layer is 2.02eV while the bandgap of
20 a $\text{Ga}_{0.5}\text{InP}_{0.5}$ lattice-matched layer is 1.87eV. Thus, the bandgap of the $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ tensile-strained layer is larger by 150meV.

While the fifth construction has been explained based on the fourth construction that uses
25 AlGaInP layer as the low refractive index layer

closest to the active layer, similar effect as in the case of using AlGaInP for the cladding layer and the material of GaInPAs system for the barrier layer and the quantum well active layer, is attained also in
5 the case of the first through third constructions, in which a part of the spacer layer provided between the active layer and the reflector is formed of the AlGaInP layer, the quantum well active layer is formed of $\text{Ga}_c\text{In}_{1-c}\text{P}_d\text{As}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$) and the
10 barrier layer is formed of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$).

Thus, in the third construction, it is possible to construct the surface-emission laser diode such that there is provided a spacer layer
15 between the active layer and the upper reflector and/or the lower reflector, a part of the spacer layer is formed of the AlGaInP layer, the quantum well active is formed of $\text{Ga}_c\text{In}_{1-c}\text{P}_d\text{As}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$), and the barrier layer is formed of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$).
20

Thus, by using the spacer layer of the composition $(\text{Al}_{a'}\text{Ga}_{1-a'})_{b'}\text{In}_{1-b'}\text{P}$ ($0 \leq a' \leq 1$, $0 \leq b' \leq 1$), it becomes possible to secure a very large bandgap difference between the spacer layer and the quantum
25 well active layer as compared with the case of

forming the spacer layer by the material of the AlGaAs system. Further, by using a compressive strain composition for the quantum well active layer, the threshold value is decreased and the efficiency of laser oscillation is improved. Thereby, it becomes possible to operate the surface-emission laser diode with high output power.

Further, as a result of improvement of the carrier confinement efficiency and as a result of decrease of the threshold value attained by the gain increase caused by the use of the strained quantum well active layer, it becomes possible to reduce the reflectivity of the DBR 305 at the optical exit side, and it becomes possible to increase the optical output further. Further, as a result of the use of $\text{Ga}_c\text{In}_{1-c}\text{P}_d\text{As}_{1-d}$ ($0 \leq c \leq 1$, $0 \leq d \leq 1$) for the quantum well active layer and as a result of the use of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($0 \leq e \leq 1$, $0 \leq f \leq 1$) for the barrier layer, It becomes possible to realize a long lifetime surface-emission laser diode in which the active layer is formed of the material free from Al and incorporation of oxygen into the active layer is reduced and formation of the non-optical recombination center is suppressed.

Thus, according to the present

construction, a highly reliable high output power surface-emission laser diode operating at the wavelength of shorter than 850nm is obtained with high active layer gain and low threshold value.

5 (6) Sixth Construction

The surface-emission laser diode according to the sixth construction of the twelfth mode of the present invention is a surface-emission laser diode of the fifth construction, wherein the oscillation
10 wavelength is longer than about 680nm.

Comparing the surface-emission laser diode with the 780nm surface-emission laser diode having the active layer of the AlGaAs/AlGaAs system, it can be seen that the bandgap difference between the
15 $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.6$, $E_g=2.0226\text{eV}$), which provides the largest bandgap in the typical compositional range of the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) system spacer layer used with the surface-emission laser diode of the AlGaAs/AlGaAs system, and the active layer of the compositional
20 wavelength of 780nm ($E_g=1.5567\text{eV}$) is generally equal to the bandgap difference (460meV) between $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($a=0.7$, $b=0.5$, $E_g=2.289\text{eV}$), which provides the largest bandgap in the typical compositional range of the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1$, $0 \leq b \leq 1$) spacer
25 layer used with the surface emission laser diode of

the present mode and the active layer of the
compositional wavelength of 680nm ($E_g=1.8233\text{eV}$).

Further, with regard to the bandgap
difference between the barrier layer and the quantum
5 well active layer, it should be noted that the
bandgap difference to the active layer of the
compositional wavelength of 680nm becomes about
200meV, assuming that the barrier layer has the
composition $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($e=0.6$, $f=1$, $E_g=2.02\text{eV}$),
10 while this is generally equal to the case of the
780nm surface-emission laser diode of the active
layer of the AlGaAs/AlGaAs system.

This means, that by using the spacer layer
of the AlGaInP system, it becomes possible to achieve
15 the carrier confinement equivalent or larger than the
surface-emission laser diode of 780nm that uses the
AlGaAs/AlGaAs system active layer, even in the case
the surface-emission laser diode is the one that uses
the Al-free active layer (quantum well active layer
20 and the barrier layer), as long as the compositional
wavelength is longer than 680nm. In practice, the
characteristics equivalent or more are attained in
view of the effect of the strained quantum well
active layer.

25 (7) Seventh Construction

The surface-emission laser diode according to the seventh example of the twelfth mode of the present invention is a surface-emission laser diode of any of the first through sixth constructions, 5 wherein the surface orientation of the substrate, on which growth is to be made, is formed a (100) surface inclined in the direction of (111)A surface within the range of 5° to 20° .

In the crystal growth of the material that 10 contains Al, In and P or GaInP, it is preferable to use a (100) GaAs substrate having a surface orientation inclined in the direction of a (111)A surface by an angle (inclination angle) of the range of 5° to 20° for the substrate 41. The reason of this 15 is that, when the surface orientation of the substrate is close to (100), there is caused problems such as decrease of bandgap by formation of natural superlattices, deterioration of surface morphology caused by hillock (hill-like defect), formation of 20 non-optical recombination centers, and the like, and there is a possibility that the device characteristics of the laser diode formed on the substrate is adversely affected.

When the surface orientation of the 25 substrate is inclined from (100) surface to the

direction of (111)A surface, on the other hand,
formation of the natural superlattice is suppressed
in correspondence to the inclination angle. Thus, the
bandgap changes sharply in the range of the
5 inclination angle of 10° to 15° , and thereafter, the
band gap approaches the nominal bandgap (bandgap
value of the mixed crystal). Further, formation of
hillocks is gradually suppressed.

On the other hand, when the inclination
10 angle in the direction of (111)A surface exceeds 20° ,
crystal growth on the substrate becomes difficult.
Thus, with the red color laser (630nm to 680nm) that
uses the AlGaInP material, the substrate inclined to
the angle in the range of 5° to 20° (in many cases in
15 the range of 7° to 15°) is used commonly. This
applies not only to the case AlGaInP is used for the
spacer layer (cladding layer), but also to the case
in which GaInP is used for the barrier layer as in
the example of Table 2. Further, in anticipation of
20 adversary effect caused also in the case the barrier
layer and the quantum well active layer are formed of
GaInPAs, it is preferable to use a (100) GaAs
substrate having a surface orientation inclined in
the direction of (111)A surface with the angle in the
25 range of 5° to 20° (more preferably with the angle in

the range of 7° to 15°), for the growth of these materials.

With regard to the control of polarization direction, Japanese Laid-Open Patent Application 5 2001-60739 describes a polarization control technology that uses a substrate having a surface orientation inclined from (100) in the direction of (111)A surface of (111)B surface by 15° - 40° and increases the optical gain in the inclined direction 10 by utilizing the optical gain anisotropy and further by using the multiple quantum well active layer of InAlGaAs and InGaAsP having a compressive strain. . Further, Japanese Laid-Open Patent Application 2001-168461 describes the construction of forming the mesa 15 shape in a circular shape, elliptical shape or elongated circular shape and setting the direction of the major axis from (100) in the direction of (111)A surface of (111)B surface. In this case, the surface orientation of the substrate is inclined from (100) 20 in the [110] direction by 2° (including -5° - $+5^{\circ}$), and the substrate is not the one inclined in the A surface or B surface direction.

With the surface-emission laser diode according to the seventh construction of the twelfth 25 mode of the present invention, the optical gain

anisotropy caused by inclining the substrate orientation in the (111)A direction is utilized for the polarization control. However, with the present construction, it is not possible to use the
5 polarization control technology that uses the (311)B substrate and thought most promising at the present juncture. Thus, with the seventh construction, the inclination angle of the substrate is smaller (5° to 20°) than the (311)B substrate (25°), and the optical
10 gain anisotropy achieved with substrate inclination becomes inevitably small, although there are advantages such as the substrate cost is suppressed and the cleaving process is conducted easily.

Thus, with the seventh construction, this
15 decrease is compensated for by the increase of optical gain anisotropy obtained by providing a compressive strain to the quantum well active layer.

Thus, the surface-emission laser diode according to the seventh construction provides a
20 shape anisotropy with regard to the outer shape of the active layer as viewed from the optical emission direction, such that the direction in the (111)A surface is elongated. Further, the outer shape of the active layer as viewed from the optical emission
25 direction of the surface-emission laser diode is

provided with anisotropy such that the direction of the (111)A surface is elongated, the optical gain in the inclined direction ((111)A surface direction) is increased further, and the polarization
5 controllability is improved.

(THIRTEENTH MODE)

Hereinafter, a surface-emission laser 400 according to a thirteenth mode of the present invention will be explained with reference to Figures
10 17 through 19.

The thirteenth mode gives more concrete shape of the first construction of the twelfth mode, wherein Figure 17 shows the surface-emission laser diode 400 in a cross-sectional view for explanation
15 of the principle, while Figure 18 is a cross-sectional view showing the active layer and its periphery of the surface-emission laser diode 400 with enlarged scale. Further, Figure 19 is a plan view showing a part of the surface-emission laser
20 diode 400.

The surface-emission laser diode 400 of the thirteenth aspect of the present invention uses an n-(100)GaAs substrate 411 having a surface orientation inclined in a direction of (111)A surface with an
25 inclination angle 15° , and on the GaAs substrate 411,

there is formed an n-semiconductor distributed Bragg reflector (lower reflector) 414 by a periodic structure 412 in which an n- $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ layer and an n- $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ layer are stacked alternately for 35
5 periods with the thickness corresponding to $1/4$ times the oscillation wavelength in the medium, wherein there is formed an n- $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ low refractive index layer 413 on the periodic structure 412 with the thickness of the $1/4$ wavelength is formed.

10 Further, there is interposed a compositional graded layer (not shown) of the thickness of 20nm and having the Al content changed gradually from one value to the other value between the n- $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ layer and the n- $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ layer
15 constituting one unit of repetition in the periodic structure 412, wherein the thickness of the foregoing unit including the compositional graded layer is set to be equal to $1/4$ times the oscillation wavelength in the medium. With such a construction, the band
20 discontinuity between the high refractive index layer and the low refractive index layer is smoothed at the time of causing to flow current to the DBR, and increase of electric resistance can suppressed.

Further, on the periodic structure 412,
25 there are stacked consecutively: an $(\text{Al}_{0.2}\text{Ga}_{0.8})_{0.5}\text{In}_{0.5}\text{P}$

lower first spacer layer 415 that achieves lattice matching to the substrate 411; an active layer 418 in which three GaInPAs quantum well active layers 415 having a compressive strain composition and the
5 bandgap wavelength of 780nm and four $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ barrier layers 417 achieving lattice matching to the substrate 411 are stacked alternately; and an $(\text{Al}_{0.2}\text{Ga}_{0.8})_{0.5}\text{In}_{0.5}\text{P}$ upper first spacer 419.

Further, on the upper spacer layer 419,
10 there is formed a p-semiconductor distributed Bragg reflector (422) formed of a p- $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ low refractive index layer (serving also for the cladding layer) having the thickness of 1/4 times the laser oscillation wavelength in that medium and a periodic
15 structure 412 in which a p- $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.9$) low refractive index layer and a p- $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.3$) high refractive index layer are stacked alternately for 24.5 periods, for example (details are omitted in Figure 1). Here, a compositional graded layer similar
20 to the lower reflector 414 is interposed between the high refractive index layer and the low refractive index layer in the upper reflector 422.

Further, a p-GaAs contact layer 423 is formed on the uppermost part of the upper reflector
25 422 for achieving ohmic contact with the electrode.

With such a construction, there is formed a cavity region 424 of one oscillation wavelength (so-called lambda cavity) between the lower reflector 414 and the upper reflector 422. Thereby, the cavity
5 region 424 forms, together with the lower reflector 414, the upper reflector 424, the cavity structure of the surface-emission laser 400.

With the surface-emission laser diode 400 according to the thirteenth mode of the present
10 invention, the interface 426 (corresponds to interface 3 of Figure 15) between the p-
($\text{Al}_{0.7}\text{Ga}_{0.3}$) $_{0.5}\text{In}_{0.5}\text{P}$ low refractive index layer (functioning also as cladding layer) 420 and the p-
 $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.3$) 425 formed on the low-refractive
15 index layer 450 and constituting the upper reflector 422 is located coincident to the node of the electric field strength distribution.

Conventionally, the AlGaInP cladding layer (spacer layer) is formed in the uppermost part of the
20 cavity region. With such a structure, the interface between the cavity region and the upper reflector of the material of the AlGaAs system is formed at the location of the anti-node where the effect of optical absorption is large. However, in the case of growing
25 a semiconductor layer containing Al, Ga and As as the

major components on the semiconductor layer containing Al, In and P as the major components, there tends to occur segregation of In such as carry over of In, and it has been difficult to suppress the
5 increase of the threshold value.

According to the thirteenth mode of the present invention in which the interface 426 is coincident to the node of the electric field strength distribution, the effect of optical absorption at the
10 interface 426 is reduced significantly, and it becomes possible to suppress the increase of the threshold value effectively even when there is caused some segregation of In in this part. It should be noted that increase of the threshold value is
15 suppressed further effectively when the segregation of In is suppressed by providing a thin (Al)GaInP between the $p\text{-(Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ low refractive index layer 420 and the $p\text{-Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.3$) layer 425 as an In segregation suppressor layer.

20 Further, it should be noted that, while the thirteenth mode uses the $(\text{Al}_{0.7}\text{Ga}_{0.3})\text{In}_{0.5}\text{P}$ layer for the low refractive index layer of the lower reflector 414 closest to the active layer 18 in viewpoint of providing symmetry to the laser structure, it is
25 possible to use the material of AlGaAs system as long

as the problem of segregation of In is to be attended.

Hereinafter, the fabrication process of the surface-emission laser diode 400 of the thirteenth mode will be explained.

With the present embodiment, the growth of the semiconductor stacked structure constituting the surface-emission laser diode 400 is conducted by an MOCVD process. Thereby, TMG (trimethyl gallium), TMA (trimethyl aluminum), TMI (trimethyl indium), PH_3 (phosphine), and AsH_3 (arsine) are used for the source, and H_2Se (hydrogen selenide) is used for the n-type dopant. Further, DMZn or CBr_4 is used for the p-type dopant. Further, H_2 is used for the carrier gas.

Because it is possible to form the construction such as a compositional graded layer by controlling the supply amount of the source gases, MOCVD process is particularly suitable for the crystal growth method of a surface-emission laser diode that includes DBR. Further, it does not require high vacuum state as in the case of MBE process and it is sufficient to merely control the supply flow rate of the source gases and the supply time, MOCVD process is suited for mass production.

With the thirteenth mode, it should be noted that a part of the low refractive index layer of the p-side DBR close to the active layer 418 is formed by an AlAs layer.

5 Further, the stacked structure thus formed is subjected to a mesa etching, there is formed a mesa structure 426 of a predetermined size such that at lease a sidewall surface of the p-AlAs layer 427 is exposed. Further, the AlAs layer thus exposed is
10 oxidized in water vapor ambient, starting from the exposed sidewall surface, and there is formed an Al_xO_y current confinement layer 428.

 Further, the space surrounding the mesa structure 426 is filled with a polyimide film 432 for
15 planarization, and thereafter, the polyimide film 432 is removed from the contact layer 423 in the part corresponding to the optical exit window 429. Further, a p-side electrode 430 is formed on the p-contact layer 423 so as to avoid the optical exit
20 part 29. Further, an n-side electrode 431 is formed on the rear side of the substrate 411.

 With the surface emission laser 400 of the present mode, current confinement is achieved by selective oxidation of the layer for selective
25 oxidation 427 that contains Al and As as the major

components, and with this, threshold current is reduced significantly.

With the current confinement structure that uses an Al oxide film formed by selective oxidation of the layer for selective oxidation 427, it becomes possible to form the current confinement layer 428 near the active layer 418, and diffusion of the injected holes is suppressed, and it becomes possible to efficiently confine the carriers into a minute region not exposed to the air.

Further, with such a current confinement structure, there occurs a decrease of refractive index when the oxidized part 428 is changed to an Al oxide film, and it becomes possible to confine the light to the minute region where the carriers are confined by way of convex lens effect. Thereby, a very large efficiency is realized, and with this, the threshold current is decreased. Further, such a current confinement structure can be easily formed, and it becomes possible to reduce the production cost of the surface-emission laser diode significantly.

Further, with the present mode, the mesa shape as viewed from the direction of optical emission is formed to have anisotropy in that the mesa structure has an elongated elliptic shape in the

direction of the (111)A surface as shown in Figure 19. Such anisotropic shape is not limited to the elliptic shape, and it is also possible to use other shapes such as a rectangular shape. With this, the
5 current injection region formed in the Al oxide film 428 becomes an elongated shape in the direction of the (111)A surface.

Further, with the surface-emission laser diode 400 of the thirteenth mode, which uses the
10 material of the AlGaInP system for the low-refractive index layer of the reflector 422 closest to the active layer 418 and for the spacer layers 419 and GaInPAs for the barrier layer 417 or the quantum well active layer 416. Thereby, the laser structure is
15 formed on the (100) GaAs substrate of the surface orientation inclined in the (111)A direction by 15° , and thus, it becomes possible to suppress the narrowing of bandgap associated with formation of natural superlattices, deterioration of surface
20 morphology caused by hillock (hill-like defect) formation, or the effect of non-optical recombination centers.

Further, with the foregoing construction, it should be noted that $(\text{Al}_{0.7}\text{Ga})_{0.5}\text{In}_{0.5}\text{P}$, which is a
25 widegap material, is used for the cladding layer (the

low refractive index layer of the reflector 422
closest to the active layer 418). Because of this, a
very large bandgap difference of 743meV is obtained
between the cladding layer 420 and the active layer
5 418 as compared with the bandgap difference of 466meV
(Al content 0.6) for the case the cladding layer 420
is formed of AlGaAs. Similarly, a large bandgap
difference is secured between the barrier layer 417
and the active layer 418, and excellent carrier
10 confinement is realized. Further, because the active
layer 418 accumulates therein a compressive strain,
it is also attained the increase of gain caused by
band splitting of heavy holes and light holes.

With these effects, the surface-emission
15 laser diode 400 has a very high gain and it is
possible to perform high output power operation at
low threshold.

While it was explained for the case of
providing a single layer of $(\text{Al}_{0.2}\text{Ga}_{0.8})_{0.5}\text{In}_{0.5}\text{P}$ layer
20 419 as the spacer layer between the $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$
low refractive index layer and the active layer 418,
it is also possible to form the space layer by plural
semiconductor layers. Further, the AlGaInP low
refractive index layer 420 or the AlGaInP spacer
25 layer may contain other constituent elements with a

trace amount.

Further, because the active layer 418 and the barrier layer 417 are formed of the material free from Al, the active region (quantum well active layer and adjacent layers) is free from Al, and
5 incorporation of oxygen is reduced with the surface-emission laser diode 400. Thereby, it becomes possible to suppress formation of non-optical recombination centers. With this, it becomes possible
10 to realize a surface-emission laser diode of long lifetime.

Further, with the surface-emission laser diode 400, control of polarization direction is achieved by utilizing the optical gain anisotropy
15 caused by inclination of the substrate 411.

Therefore, with the surface-emission laser diode 400 of the present embodiment, the inclination angle of the substrate is small (15°) when compared with the surface-emission laser diode that uses the
20 (311)B substrate (inclination angle 25°), which is thought most promising at the present juncture.

Thus, with the present mode, this decrease of the optical gain anisotropy is compensated for by the increase of the optical gain anisotropy caused by
25 providing a compressive strain to the quantum well

active layer 416, and by forming the outer shape of the quantum well active layer 416 so as to extend in the direction of the (111)A surface for increasing the optical gain in the substrate inclination direction (direction of (111)A). With such a construction, it becomes possible to realize a polarization control not inferior to the case of using the (311)B substrate.

Thus, according to thirteenth mode of the present invention, it becomes possible to realize a high output power surface-emission laser diode of 780nm wavelength band having large gain, low threshold value, good reliability and controlled polarization direction. Thereby, the surface-emission laser diode 400 of the present embodiment is designed to the structure in which the increase of threshold value is retarded even when there is caused segregation of In at the time of conducting crystal growth of the semiconductor layer 425 containing Al, Ga and As as the major components on the semiconductor layer 420 that contains Al, In and P as the major components. Thereby, production of the laser diode can be conducted easily.

It should be noted that the foregoing effect of the present invention of Al-free active

layer decreases at shorter wavelength band, but it appears conspicuously as long as the oscillation wavelength is longer than 680nm.

For example, when compared with the
5 surface-emission laser diode of the 780nm band that uses the active layer of AlGaAs/AlGaAs system, it should be noted that the bandgap difference between the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.6$, $E_g=2.0226\text{eV}$) having the largest bandgap in the typical compositional range used for
10 $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 < x \leq 1$) system spacer layer used with the surface-emission laser diode of the AlGaAs/AlGaAs system and the active layer of the compositional wavelength 780nm ($E_g=1.5567\text{eV}$), is generally equal to the bandgap difference (460meV) between the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($a=0.7$, $b=0.5$, $E_g=2.289\text{eV}$) having the
15 largest bandgap in the typical compositional range used for the $(\text{Al}_a\text{Ga}_{1-a})_b\text{In}_{1-b}\text{P}$ ($0 < a \leq 1, 0 \leq b \leq 1$) spacer layer and the active layer of the compositional wavelength of 680nm ($E_g=1.8233\text{eV}$).

20 Further, with regard to the bandgap difference between the barrier layer and the quantum well active layer, the bandgap different to the active layer of the compositional wavelength of 680nm becomes about 200meV when the barrier layer is formed
25 of $\text{Ga}_e\text{In}_{1-e}\text{P}_f\text{As}_{1-f}$ ($e=0.6$, $f=1$, $E_g=2.02\text{eV}$), while this

is generally equivalent to the case of the surface-emission laser diode of 780nm that uses the AlGaAs/AlGaAs system active layer.

This means that it becomes possible to
5 achieve the carrier confinement equivalent to or superior to the case of the surface-emission laser diode of the 780nm band that uses the active layer of the AlGaAs/AlGaAs system while using an Al-free active layer (quantum well active layer and barrier
10 layer) by using the spacer layer of the AlGaInP system, provided that the compositional wavelength is longer than 680nm. In fact, the effect of the strained quantum well active layer is added, and it is possible to obtain the characteristics exceeding
15 the surface-emission laser diode of the AlGaAs/AlGaAs system.

Further, when Al is incorporated to the barrier layer 417, it becomes possible to fabricate a red color surface-emission laser diode of the
20 wavelength shorter than 680nm such as the device of the 650nm band. In this case, the effect of Al-free active layer is not attained, but it becomes possible to improve the problem of segregation of In noted before.

25 (FOURTEENTH MODE)

Next, a fourteenth mode of the present invention will be explained with reference to Figure 20. It should be noted that the fourteenth mode relates to the construction that gives practical
5 shape to the third construction mentioned before.

Figure 20 is a cross-sectional view showing the part around the active layer of a surface-emission laser diode 500 of the present mode in an enlarged scale.

10 Referring to Figure 20, the present embodiment has the construction similar to that of the thirteenth mode of Figure 18, except that a barrier layer 417a of $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ having a tensile strain is used in place of the barrier layer 417.

15 In the material of the GaInPAs system used for the barrier layer of the quantum well active layer in the surface-emission laser diode, GaInP has the largest bandgap when compared with the same lattice constant. Further, a larger bandgap is
20 obtained with the material having a smaller lattice constant. Thus, by using a material of the GaInP system of small lattice constant for the barrier layer, it is possible to realize a large band discontinuity between the barrier layer and the
25 quantum well active layer, and it becomes possible to

increase the gain of the surface-emission laser diode. With this, the surface-emission laser diode can perform high output power operation with low threshold value. For example, it should be noted that
5 the bandgap of the tensile-strained $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ layer is 2.02eV, the bandgap of the $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ lattice matched layer is 1.87eV, and thus the $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ tensile strain layer has a bandgap larger by 150meV.

It should be noted that the effect of
10 increasing the band discontinuity by using a tensile composition layer for the barrier layer is obtained not only when the quantum well active layer has a compressive composition but also in the case it has the lattice-matched composition or tensile
15 composition.

(FIFTEENTH MODE)

The surface-emission laser diode according to the fifteenth mode of the present invention has a construction similar to that of the surface-emission
20 laser diode 400 according to the thirteenth mode explained with reference to Figure 18, except that C is used for the dopant of the multilayer structure of the p-semiconductor distributed Bragg reflector formed of $\text{p-Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.9$) and $\text{p-Al}_x\text{Ga}_{1-x}\text{As}$ ($x=0.3$)
25 and Mg is used for the dopant of the p-

$(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ low refractive index layer.

Zn (zinc) is used extensively for the p-type dopant of $(\text{Al})\text{GaInP}$ layer, while Zn has a large diffusion coefficient and easily causes diffusion to the active layer or to the neighbor of the active layer during the growth process of the upper reflector. Thereby, there is caused deterioration of crystal quality in the active layer, resulting in degradation of the device characteristics such as decrease of efficiency of optical emission or increase of absorption loss. This problem becomes particularly serious when the p-side semiconductor layer is formed underside of the active layer.

Further, the surface-emission laser diode has a film thickness several times larger than that of an edge-emission laser diode and thus requires longer growth time. Thus the problem of thermal diffusion is by no means a problem that can be neglected.

Mg has a smaller diffusion coefficient than Zn and it is thought that use of Mg can improve the foregoing problem. On the other hand, with the semiconductor layer containing Al, Ga and As as the major components, the diffusion coefficient of C is smaller than the diffusion coefficient of Mg.

Further, it is known that controllability becomes poor when Mg is added to the material of the As system.

Thus, with the present embodiment, Mg is added to the AlGaInP layer and C is added to the AlGaAs multilayer film. With this, the problem of dopant diffusion or memory effect can be reduced, and it becomes possible to carry out doping with good controllability. Thereby, a doping profile close to the designed profile is obtained, and at the same time, degradation of the crystal quality of the active layer is suppressed. With this, it becomes possible to achieve low threshold value and high output operation in the surface-emission laser diode.

It should be noted that the effect of using Mg for the dopant of the AlGaInP film and C for the dopant of the AlGaAs film is obtained not only in the case of using the AlGaInP film as the low refractive index layer of the reflector, but also in the case the AlGaInP film is provided in the cavity region sandwiched between the upper and lower reflectors as shown in Figure 21. Further, similar effect is obtained also in the case of forming the cavity region by the material of the AlGaInP system similarly to the present mode and the reflector is

formed of the material of the AlGaAs system as in the case of the surface-emission laser diode of the 650nm visible wavelength band.

In the construction of Figure 21, it should
5 be noted that an $n\text{-(Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ cladding layer 512 is formed on an $n\text{-Al}_{0.9}\text{Ga}_{0.1}\text{As}$ layer 511 constituting the uppermost low refractive index layer of the n-type lower reflector, and an active layer is formed on the n-type cladding layer 512 via a
10 $(\text{Al}_{0.2}\text{Ga}_{0.8})_{0.5}\text{In}_{0.5}\text{P}$ lower spacer layer 514 in the form of alternate stacking of the GaInPAs quantum active layer 514 accumulating therein a compressive strain and a $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ barrier layer 515, and wherein there is further formed a $p\text{-(Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ cladding
15 layer 517 on the active layer via a $(\text{Al}_{0.2}\text{Ga}_{0.8})_{0.5}\text{In}_{0.5}\text{P}$ upper spacer layer 516, and the cladding layer 517 is formed with a $p\text{-Al}_{0.9}\text{Ga}_{0.1}\text{As}$ layer 518 constituting the lowermost low refractive index layer of the p-type upper reflector 518.

20 The $n\text{-Al}_{0.9}\text{Ga}_{0.1}\text{As}$ layer 511 and $p\text{-Al}_{0.9}\text{Ga}_{0.1}\text{As}$ layer 518 have the thickness of $1/4$ times the laser oscillation wavelength in that medium, and in the illustrated example, the semiconductor layers 512 - 517 form a cavity 519 of one wavelength between the
25 upper and lower reflectors 511 and 518.

(SIXTEENTH MODE)

The surface-emission laser according to sixteenth mode of the present invention has a construction similar to that of the surface-emission
5 laser diode 400 of Figure 18, except that stacking of the $n\text{-(Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ low refractive index layer and the $p\text{-(Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ low refractive index layer at the top part of the lower reflector 413 is replaced with a short period superlattice structure
10 of $\text{Al}_{0.5}\text{In}_{0.5}\text{P}$ and $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$.

Although it changes depending on the material, thermal resistance of a semiconductor layer increases with increasing number of the elements that constitutes the semiconductor material. Thus,
15 AlGaInP , a quaternary material, has a large thermal resistance. Thus, the heat generated in such an active layer is not dissipated easily but is accumulated in the active layer and invites the temperature rise of the active layer. Thus, there has
20 been a problem that the optical output saturates with small injection current.

In the case of surface-emission laser diode, it can be regarded, when there is formed a superlattice structure by stacking the layers having
25 a thickness sufficiently smaller than the oscillating

wavelength alternately, that it is optically equivalent to the case in which there is formed a mixed crystal having an average composition by mixing these layers uniformly, although there is a report
5 that there occurs slight increase of refractive index by forming the superlattice structure. Thus, it is possible to construct a reflector by using the semiconductor layers thus constructed by the superlattice structure.

10 Here, in view of the fact that the thermal resistance of the ternary system material such as AlInP or GaInP is smaller than that of AlGaInP, a quaternary material, and because of the fact that AlInP or GaInP can be lattice-matched to the GaAs
15 substrate similarly to the case of AlGaInP, the present construction decreases the thermal resistance by forming a superlattice structure in place of the conventional AlGaInP semiconductor layer of uniform composition, by choosing at least two materials of
20 small thermal resistance as compared with the average composition. With this, the heat generated in the active layer is efficiently dissipated, and temperature rise of the active layer by current injection is decreased. Further, it becomes possible
25 to conduct the current injection with a higher level

than conventional case, while this leads to higher output, and it becomes possible to obtain a surface-emission laser diode capable of operating at high output power.

5 Meanwhile, it should be noted that the effect of thermal resistance reduction for the case of forming AlGaInP by way of short period superlattice structure of AlInP and GaInP is not limited to the case of using AlGaInP for the low
10 refractive index layer of a reflector, but it is obtained also for the case of the superlattice structure provided in the cavity region 519 sandwiched by the upper and lower reflectors 511 and 518. Further, similar effect is obtained also in the
15 surface-emission laser diode that forms the cavity region by the material of the AlGaInP system as in the case of the visible 650nm band surface-emission laser diode.

20 Further, because heat dissipation from the active layer is made primarily at the side of the substrate, it is preferable that the foregoing construction is applied at least to the AlGaInP layer at the substrate side.

(SEVENTEENTH MODE)

25 Hereinafter, a surface-emission laser diode

600 according to the seventeenth mode of the present invention will be explained with reference to Figure 22, wherein those parts of Figure 22 explained previously are designated by the same reference
5 numerals and the description thereof will be omitted.

The surface-emission laser diode 600 according to the present embodiment has a construction similar to that of the surface-emission laser diode 500 according to the fourteenth mode,
10 except for the following two points.

The first point is that the lower reflector 414 is formed of consecutive stacking, from the side of the substrate 411, of a first lower reflector 412A in which an n-AlAs low refractive index layer and an
15 $n\text{-Al}_{0.3}\text{Ga}_{0.7}\text{As}$ high refractive index layer are stacked for 31 periods, and a second lower reflector 412B in which an $n\text{-Al}_{0.9}\text{Ga}_{0.1}\text{As}$ low refractive index layer and an $n\text{-Al}_{0.3}\text{Ga}_{0.7}\text{As}$ high refractive index layer are stacked for 9 periods, and that the n-
20 $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}$ low refractive index layer 413 is formed thereon.

Because the lower reflector 414 contains AlAs of small thermal resistance as the low refractive index layer, dissipation characteristics
25 of the heat generated in the active layer 416 is

improved and the temperature rise at the time of driving is suppressed. Thereby, a high output power surface-emission laser diode of excellent temperature characteristics is obtained.

5 Meanwhile, in the case the etching surface reaches, at the time of formation of the mesa structure, the AlAs layer of the first lower reflector 412A, there proceeds oxidation also from the edge surface of the AlAs layer exposed at the
10 sidewall at the time of oxidation processing of the AlAs layer for selective oxidation to be conducted laser, and there may arise the problem that the active layer 416 is insulated or electric resistance of the laser diode is increased. This is because the
15 oxidation rate of AlGaAs depends heavily on the Al content such that the oxidation rate increases with increasing Al content and reaches maximum at the composition of AlAs.

 Because of this, with the present mode, the
20 second lower reflector 412B of AlGaAs of small oxidation rate is provided on the foregoing lower reflector 412A. It should be noted that such second lower reflector 412B becomes necessary in the case the oxidation rate of the low refractive index layer
25 of the first lower reflector 412A is formed of the

material or thickness faster than the layer for selective oxidation. For example, there are cases in which the lower refractive index of the first lower reflector 412A is larger than that of the layer for selective oxidation 427 even when Ga is contained, as
5 in the case in which the layer for selective oxidation 427 is formed of a material in which a small amount of Ga is added to AlAs. In such a case, too, the second lower reflector 412B becomes
10 necessary. As long as the low refractive index layer in the first lower reflector 412A has a composition (material) of small thermal resistance as compared with that of the low refractive index layer in the second lower reflector 412B, efficient heat
15 dissipation is realized.

In the mesa etching, there arises variation in each lot, while in the present mode, it is sufficient that the mesa etching is conducted such that the etching stops between the layer for
20 selective oxidation 427 of Al oxide and the AlAs layer 412A of the first lower reflector.

It should be noted that this mesa etching can be conducted by a reaction beam etching (RIBE) method by introducing a Cl_2 gas into the processing
25 vessel of a dry etching apparatus that holds the

substrate to be processed. During this mesa etching process, it becomes possible to monitor the progress of etching by obtaining the ratio of In emission (451nm) and Al emission (396nm) are obtained by using
5 a plasma atomic emission spectrometer as explained already with previous embodiment.

After several minutes from the start of the etching, the In emission (451nm) is detected while the In emission disappears in the meantime. Thus, by
10 terminating the etching at the moment the emission of In has disappeared, it becomes possible to stop the etching inside the second lower reflector 412B. Thereby, it becomes control the mesa etching easily with good reproducibility.

15 The second point is that there is provided a $(\text{Al}_{0.1}\text{Ga}_{0.9})_{0.5}\text{In}_{0.5}\text{P}$ intermediate layer 601 of the thickness of 20nm, for example, at the interface of the $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ high refractive index layer and the $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ low refractive index layer of both
20 n-side and p-side.

By inserting the intermediate layer 601 of low Al content, it becomes possible with the present mode to expand the range of growth condition in which planar crystal growth can be conducted with good
25 crystal quality particularly in the case of stacking

a p-Al_{0.3}Ga_{0.7}As high refractive index layer on the p-
(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P low refractive index layer, and
formation of the high refractive index layer can be
conducted easily. Further, while there arises a
5 problem of increased band discontinuity in the
valence band at the heterojunction of a material of
the AlGaAs system and a material of the AlGaInP
system, it becomes possible to reduce such band
discontinuity of the valence band by inserting such
10 an intermediate layer of low Al content, and it
becomes possible to decrease the electric resistance.
Thereby, the intermediate layer 601 may contain As.

Further, by using the surface-emission
laser diode of the twelfth through seventeenth modes
15 of the present invention, it becomes possible to
construct the surface-emission laser diode array 220,
the optical transmission module 240, the optical
communication system 260, the laser printer 280 that
uses the surface-emission laser array chip 281, or
20 the like.

Further, the present invention is not
limited to the embodiments heretofore but various
variations and modifications may be made within the
scope of the invention described in the patent
25 claims.